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# Book of Abstracts Poster

**Acevedo H. / Universidad de Colombia**

## Particle Number Measurement of Euro III Diesel buses fitted with DPF´s in the Public Transport System of Bogota D.C.

Bogota is one of the largest city in the world with a population greater than 10 million people. Nowadays, in-use diesel vehicles in the District are equipped with EURO II and III engines and will have a 10-year lifespan. The $PM_{10}$ levels are high for Bogota, and mobile sources are responsible for the emission of 1,400 tons of $PM_{10}$ per year. Since 2000, 900 Euro II articulated buses have been part of the Bus Rapid Transit (BRT) system, and 1000 Euro II and III diesel buses were added in 2005. Nowadays, the BRT system comprises ca. 8500 diesel buses, most of which are Euro II and Euro III. In 2010, the Mayor of Bogota issued a decree making the use of Diesel Particulate Filters (DPF) mandatory for all buses that are part of the public transit fleet of the city, including the BRT system. As a result, Bogota is implementing a DPF retrofit program with the support of the Swiss Agency for the Development and Cooperation. A pilot project of this program is monitoring particle number reductions in emissions from 13 old diesel buses and 2 new buses before and after the installation of DPF. So far, two Euro II and three Euro III articulated buses (160 passengers) and one Euro III bus (50 passengers) have been tested in several stages. The first stage consisted of 10-weeks of exhaust pressure and temperature data logging. In the second stage, buses have been tested under dynamometer and on-road conditions in order to determine exhaust gases and particle number emissions, before and after a 12-week period. The retrofit was successful for the Euro II articulated buses, since the DPF failed after just a few hours of operation. One of the three Euro III buses fitted with a DPF didn't have any operational problem. Premature maintenance of the DPF and installation of Diesel Oxidation Catalysts (DOC) was necessary for the other two, after three and six weeks of operation, . DPF were maintained and reinstalled and have not experienced more problems. Results show that a DPF on a Euro III articulated bus is able to reduce more than 98% of ultrafine particles without any penalty on fuel consumption. NOx emissions increased with the use of DPF. The Euro III 50 passenger bus fitted with an active DPF showed reduction of ultrafine particles by only 75%.

**Barosova H. / University of Fribourg Switzerland**

## Biological Impact of Brake Wear Particles – Aerosol Exposures onto the Surface of a 3D Human Epithelial Tissue Barrier

**Background:** Brake wear particles are becoming a significant non-exhaust traffic-related source of air-pollution and may contribute almost equally to traffic-related $PM_{10}$ emissions in comparison to exhaust related sources. The mass of brake wear particles' in total traffic-related $PM_{10}$ emissions is estimated to be up to 21%. Although exhaust emissions controls are strict, there is a lack of restrictions regarding brake pad formulations and possible release of constituents generated by associated friction processes. Human exposure to brake wear particles mainly occurs via inhalation, but the effect of brake wear particles exposure upon human lungs remains unclear and only few studies exist up to now. Therefore, the aim of this study was to mimic inhalation of brake wear particles *in vitro* and to assess their possible adverse biological impact.
**Investigation methods:** Brake wear particles released from commercially available "low-metallic" automotive brake pads were generated in a full scale automotive brake dynamometer simulating urban driving. The collected fractions were analyzed using Raman microspectroscopy and scanning electron microscopy with energy-dispersed spectrometry (SEM-EDS). A single exposure of brake wear particles was tested at different concentrations ([0.5, 1 and 2mg/ml] in medium) via the addition of 100 µl of the particle suspension onto the apical side of the *in vitro* triple cell co-culture model of the human epithelial airway barrier (consisting of A549 epithelial cells, human blood monocyte-derived macrophages and dendritic cells) at the air liquid interface (referred to as pseudo-ALI). . Cellular morphology was observed by laser scanning confocal microscopy, whilst biochemical effects associated with a (pro-) inflammatory response and oxidative stress were assessed.
**Results:** The mixture of all released fractions of brake wear particles was tested for this trial test. No change in cell morphology was observed for any condition, *i.e.* negative control and brake wear particle exposed cells. In addition, no significant effects ($p$>0.05) were observed in the release of (pro-)inflammatory mediators tumor-necrosis factor-α and interleukin-8, as well as in the intracellular antioxidant glutathione compared to the negative control.
**Conclusion:** It was possible to mimic the inhalation of brake wear particles by using an advanced lung cell model and an aerosol exposure, *i.e.* pseudo-ALI, approach. First results show that an acute exposure does not induce any adverse effects, however, further investigation using additional endpoints, particle concentrations and particles from other brake pads need to be tested to support this claim.
**Acknowledgement:** This research is financed by Sciex-NMS and Adolphe Merkle foundations.

**Beránek V. / University in Prague**

## Augmenting high-volume Atmospheric Samplers to Collect Large Amounts of Particulate Matter from Vehicle Exhaust for Toxicity Assays

Evaluation of the effects of new engine and exhaust aftertreatment technologies and new motor fuels requires not only the measurement of the emissions of regulated compounds, but also, a reasonable battery of chemical analyses and toxicological assays is beneficial. Many advanced toxicological assays, carried on as a part of evaluation of the effects of existing and new motor fuels and engine and exhaust aftertreatment technologies, require the collection of a rather large amounts of particulate matter for subsequent off-line analysis. While tens of micrograms are sufficient for gravimetric analysis, quantification of carcinogenic polyaromatic hydrocarbons requires on the order of one milligram of particulate matter, and more complex genotoxicity assays such as the RNA microarray require on the order of hundreds of milligrams of material.

Given the small size and fractal nature of diesel soot, and relatively low mass emissions of contemporary engines, collection of the required amount of material is often difficult as the ratio of accumulated mass to the filter pressure drop is relatively low.

In this work, two high-volume atmospheric samplers (EcoTech 3000, 68 m3/hour) have been augmented with an auxiliary three-stage blower (maximum pressure drop of 17 kPa at twice the sampler flow rate of 68 m3/h) and with high-strength filter holders, substantially increasing the sampler capacity.

Comparison measurements with simultaneous sampling on 47 mm diameter filters suggest that in the absence of leaks, the ratio of particle masses retained on 8“x10“ filters and 47 mm filters is generally comparable to the ratio of the sample flows through high-volume and ordinary samplers.

Allowing the samplers to run with a higher pressure drop on the filter has nearly tripled the maximum mass of the particles collected on a 20x25 cm filter, from around 7 mg to around 20 mg per filter.

The augmented samplers have been used to collects hundreds of milligrams of particles from a typical diesel engine powered by first and second generation biofuels, both neat and blended with diesel fuel.

The work was funded by the Czech Science Foundation, project BIOTOX - Mechanisms of toxicity of biofuel particulate emissions (13-01438S).

**Besch M. / West Virginia University USA**

## In-line, Real-Time Particulate Matter Sensors for OBD and Exhaust Aftertreatment System Control Applications

The ability to quantify particle mass and number concentrations within the exhaust stream of internal combustion engine equipped vehicles during in-use operation is of critical importance in order to continuously monitor and diagnose the particle matter removal efficiency of modern exhaust gas aftertreatment systems. However, in-line sensors capable of accurately measuring particulates, both on number or mass concentration basis, are an emerging technology still in its infancy, while commercially available "*near laboratory grade*" portable emissions measurement systems suffer from high complexity, bulkiness, maintenance intensity, and associated high costs for purchase and operation. There exists, therefore, a critical need to identify suitable and cost effective sensors along with evaluation procedures and to develop an in-use compliance testing methodology that bridges the gap between vehicle certification procedures and real-world operation. This is essential to guarantee adherence to particle number emissions limits set forth by the regulatory agencies and protection of the population from hazardous emissions over the entire duration of the engine and aftertreatment assembly's useful life.

The primary objective of this study was to identify a viable in-line particle matter sensor that can establish a relationship to an aerosol in real-time, thus, allow formulation of a particle number emission- based compliance metric for internal combustion engines. Furthermore, successful implementation of such an in-line particle sensor will not only allow for continuous monitoring capabilities of the aftertreatment system's particle filtration efficiency, but also provide regulatory agencies with a simplified tool to assess real-world particle number emissions in order to verify in-use compliance of internal combustion engine powered vehicles. In depth literature analysis suggested a sensor operating on the diffusion-charging principle of particles being optimally suited to be employed within the exhaust gas stream to accurately quantify particle number emissions for on-board diagnostics and in-use compliance applications.

The specific aims of this study included the development of a calibration algorithm for a diffusion-charging type in-line particulate sensor to quantify real-time particle mass and number concentrations as well as the proof of concept of an in-use compliance testing methodology based on the use of aforementioned diffusion-charging type particulate sensor. The calibration and evaluation of the sensor followed a three tier process, ranging from fundamental sensor response analysis using an AVL particle generator to develop and parameterize the underlying physical phenomena of the measurement principle, over '*controlled environment*' engine dynamometer experiments to more real-world like chassis dynamometer testing. Finally, the sensor was installed on both heavy and light-duty test vehicles that were being operated over diverse driving conditions, and compared to commercially available portable emissions measurement systems as well as to the standard regulatory gravimetric particulate matter measurement method. Additionally, a method based on recurrence analysis of the particle sen

**Bharat Lal Sahu / Pt Ravishankar Shukla University, India**

## Characterization of Mosquito Coil and Incense Aerosols

### Background

The coils and incense materials are fumed to repel mosquito and to fragrant the environments in the Asia. They contribute significantly to the indoor air pollution and their smokes caused toxicological effects [1-2]. They are made of wood, charcoal, starch, oil and adhesive or binding materials. In addition, some ingredients i.e. allethrin, sodium benzoate, potassium nitrate, etc. are mixed in the mosquito coils. Hence, in the present work, segregation and chemical characterization of particulates in 8 modes i.e. $PM_{10.0-9.0}$, $PM_{9.0-5.8}$, $PM_{5.8-4.7}$, $PM_{4.7-3.3}$, $PM_{3.3-2.1}$, $PM_{2.1-1.1}$, $PM_{1.1-0.7}$ and $PM_{0.7-0}$ are described.

### Experimental

The 8-stages Anderson sampler was used for segregation of the $PM_{10}$ in January 2013. The $PM_{10}$ were collected by using Partisol sampler on 47-mm quartz fibre filters (Whatmann, QMA) housed in the moulded filter cassettes. The air sampler was operated at flow rates of 20 l $min^{-1}$. The flux of $PM_{10}$ was measured by burning the materials in a closed chamber (0.5x0.5x0.5 $m^3$) equipped with the exhaust fan and UC Davis (USA) portable air sampler.

### Results and discussion

The most of the fractions of the $PM_{10}$ lie in the ultrafine modes during their burnings, **Figures 1-2**. The concentration of PM during their fuming lie above 1000 µg $m^{-3}$. The emission fluxes for the PM during combustions was found > 20 g $kg^{-1}$ of the coil. The higher PM fluxes was observed in the case of the mosquito coil due to ingredients i.e. sodium benzoate, potassium nitrate, etc. The content of $Cl^-$, $NO_3^-$, $SO_4^{2-}$, $NH_4^+$, $Na^+$, $K^+$, $Mg^{2+}$ and $Ca^{2+}$ in the incense particulates was found to be (n = 4) 2.9, 1.8, 1.3, 0.1, 0.5, 3.3, 0.5 and 2.1 g $kg^{-1}$, respectively. However, several folds higher content of ions in the mosquito coil PM was observed due to mixing of ingredients in the coil. The fraction of ions i.e. . $Cl^-$, $NO_3^-$, $SO_4^{2-}$, $NH_4^+$, $Na^+$, $K^+$, $Mg^{2+}$ and $Ca^{2+}$ (n = 4) in the mosquito coil PM was 6.5, 2.5, 7.1, 0.2, 1.1, 3.9, 02 and 1.8%, respectively. The equivalent concentration ratio of the [∑anion]/ [∑cation] in the incense and mosquito particulates was found to be 0.5±0.3 and 1.8±0.9, respectively. The acidic environment was observed in the mosquito particulates due to presence of excessive fraction of $Cl^-$ and $SO_4^{2-}$. The ions in the incense particulates had good correlation, indicating origin during combustion processes. However, in the case of mosquito coil, the ions showed no correlation, may be due to mixing of salts of Na and K as ingredients.

### Conclusion

The ultra fine particulates dominate during fuming of the both materials. The higher concentration of ions (i.e. $Cl^-$ and $SO_4^{2-}$) in the mosquito particulates is seen to be responsible for making the acidic particulate environment. Several folds higher content of ions the mosquito coil PM was observed due to mixing of the salts as ingredient.

**Booker D. / Sensors USA**

## The Development and Characterisation of a PEMs PMP-Compliant CPC-based Particle Counter for Real World on-Vehicle Measurements

Within the framework of the proposed new RDE / LDV European Light-Duty PEMs testing, the EU - JRC has been evaluating candidate technology platforms for on-board particle number measurements. These technologies have included diffusion-charge- (DC's) and CPC-based solutions. Although diffusion-charge based systems have been used to measure particle number concentrations with various degrees of success from vehicles, their correlation to the reference laboratory-based CPC-based PNP device have a number of intrinsic drawbacks that are difficult to overcome; notably, particle size dependence ($d^{(1.2-1.4}$)and particle composition/morphology artifacts. Moreover, the difficulties in the operating commercially-available CPC's on-vehicle that mitigate the safety concerns of the operating fluid, meet the thermal requirements, have appropriate thermal sample conditioning of the aerosol and can operate under the challenging environment (for example, shock, vibration and altitude) has necessitated the development of a new portable mixing-type CPC with sampling conditioning similar to that used in the reference PMP devices.
The new compact 12V device comprises a modular heated line (ca 200 °C), a heated primary dilution system (200 °C, nominally set at 15:1) a VPR (heated catalyst ca 300 °C), a diffusion screen size classifier for the removal of all sub 23nm particles) a secondary diluter system (100-200:1) and a mixing-type CPC operating using n-butanol.
This system has been characterized in accordance with the EU PMP guidelines and shown to meet the required criteria: removal of volatiles, particle size penetration efficiency and linearity. In addition to these criteria, the system has been evaluated over a range of real-world driving conditions (notably, vibration, temperature and altitude) for any additional error sources. For example, particle losses (diffusion and thermophoresis) have been determined over the wide ranging exhaust temperature changes as well as a function of different sampling geometries that would be required to fulfil PEMS installation on different vehicle types.

This presentation will cover the key design features and demonstrate, using a combination of both laboratory tests and on-road tests, the viability of using a CPC device on-vehicle for regulatory driven PN measurements as well as for the support of vehicle powertrain development.

**Brem B. / EMPA Switzerland**

## Sensitivity of Aircraft Gas Turbine non- volatile Particulate Matter Mass and Number Emissions to Fuel Aromatic Content

Particulate matter (PM) emissions from aircraft gas turbines are a concern for human health, environmental degradation and climate change. Understanding the effect of aromatics in the fuel on non-volatile particle matter (nvPM) emissions is important for establishing future regulation and for assessing potential future emission abatement strategies that intend to change fuel feedstock. This work presents non-volatile PM mass and number emission indices (EIs, mass or number nvPM/ mass fuel) as a function of fuel aromatic content for an aircraft gas turbine source with a modern rich-quench-lean (RQL) combustor run under certification-like conditions in the test cell of SR Technics, Zurich airport.
The nvPM sampling system and system operation corresponded to the recently issued standard[1] and are only briefly outlined here. PM laden exhaust was continuously sampled by a single point retractable Inconel sampling probe at the engine exit plane. The aerosol sampled was then diluted with dry nitrogen or synthetic air by a factor of eight to ten and transported via temperature-controlled lines to minimize condensation, particle agglomeration, and gas-to-particle conversion. NvPM mass was determined with a micro soot sensor (MSS, Model 483, AVL Inc.). In parallel to the MSS, an AVL particle counter (APC) and a $CO_2$ analyzer (Model 410i, Thermo Inc.) provided PM number and $CO_2$ concentrations emitted. The fuel (JET A-1) total aromatics level was changed by a controlled injection of two aromatic solvents into the fuel supply line to the engine. The two aromatic solvents were Solvesso 150 and Solvesso 150ND, of which the first one contained 6% by volume naphthalenes. Besides the unmixed fuel that had a total aromatic content of 17.8 % by volume, three fuel blending ratios covering the range up to 23.6% by volume in total aromatic content were tested for each solvent at six static engine thrust points ranging from idle to take-off.
The results show a clear increase in nvPM mass and number EIs with increasing fuel aromatics content. The most pronounced increase in EI (up to +60% for mass and +50% for number) was found at low combustor inlet pressure and temperature (low thrusts), indicating that fuel aromatics have an important impact on soot formation under this condition. At the engine thrust near take-off, the nvPM EIs increased by 5 – 10% for number and 10 - 20% for mass, indicating a less significant effect of fuel aromatics on the soot formation. Increasing naphthalenes from 0.78%Vol to 1.18%Vol while keeping the total aromatics constant resulted in an additional increase of nvPM mass and number EIs in the order of 10 – 15%.A good correlation between normalized nvPM EIs and fuel hydrogen mass content was found (Figure 1).

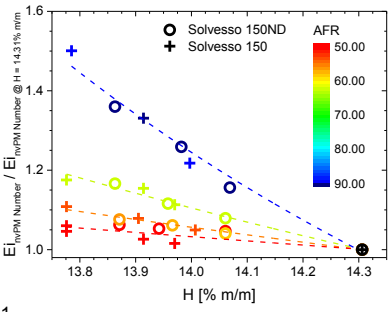


**Figure 1 Change in number emissions as a function of fuel hydrogen mass content and engine air to fuel ratio (AFR, proxy for engine static thrust)**

Using the relationship in Figure 1 could be an approach to correct EIs under certification condition to a specified reference or for generally assessing aviation environmental impacts.

[1]SAE AIR6241

**Byeongiu Jeong / Korea University of Technology and Education**

## The Effect of a Thermal Denuder on the Measurement of Black Carbon Generated in a Diesel Engine

Black carbon (BC) has been studied for many years since it was known to act as a positive radiative forcing. Not only the environmental implication but also a health concern of diesel exhaust as carcinogenic creates necessity for the research of the BC. The BC is prevalent in the ambient aerosol due to the soot generated in diesel engines. In this situation, we have initiated the investigation of the effect of a thermal denuder on the measurement of BC. Usually, mass concentration of BC is measured without removing any volatile compounds. The BC is produced due to incomplete combustion in flames, engine and so forth. The BC may contain volatile compounds, which cause bias for the measurement, especially for the filter-based techniques due to the intrinsic nature of the filter itself. In this research, we show that the BC concentration measurement is affected by the installation of thermal denuder in front of the measurement instrument. We employed a Multi-angle absorption photometer (MAAP) to measure the BC. The diesel BC was produced from a commercially available 2.0L variable-geometry turbocharger (VGT) diesel sport utility vehicle (SUV) and was introduced into MAAP through a sample inlet. The diesel BC was monitored in real time. A home-made thermal denuder was installed in front of the BC measurement instrument. The temperature of the thermal denuder was controlled at approximately 100~200 degC, where the volatile compounds included in the diesel exhaust are supposed to be removed. BC concentration measured with the thermal denuder was compared to that measured without the thermal denuder for the idle condition and no load condition. The BC concentrations were reduced as soon as the thermal denuder was operated. However, the BC concentration was increased back to the value that was measured when the thermal denuder was not operated. Further study will be continued to elucidate the remaining questions.

**Cachón L. / TESTO, Germany**

## Second generation of Diffusion Size Classifier for Oncoming Motor Vehicle Regulations

Particle counting on diesel light-duty vehicles is mandatory in Europe for type approval through Euro 5b since September 2011 and has been also introduced for GDI technology through Euro 6 by September 2014. The European Union and other countries worldwide will continue to integrate particle counting into their emission standards, especially since the World Health Organization reclassified diesel engine exhaust as 'carcinogenic to humans'. Last September, according to this strategy, the European Commission has proposed particle counting for several categories of internal combustion engines for non-road mobile machinery. Moreover, the Commission is working on the technical assessment of PEMS for particle number emitted by light-duty vehicles under real world conditions. In Switzerland the periodic control of the construction machinery on field is mandatory since January 2013. As result, the oncoming test procedures for different vehicles categories may include on-road measurements and periodic control of particle emissions requesting suitable technology as an extension of the Particle Measurement Program (PMP).

With an eye on real driving measurements of ultrafine particles proposed in forthcoming European Emission Standards and periodic control on the field, Testo AG is developing portable instrumentation for solid nanoparticle counting and classification. This innovative instrumentation based on second generation of Diffusion Size Classifier technology measures number concentration, average diameter and LDSA in a wide range under real world conditions. This presentation aims to show the technology performance, functionality and the calibration procedure followed by some results from comparisons with traditional aerosol instruments in the laboratory and on-road.

The portable nanoparticle instrumentation based on diffusion charging constitutes a new measuring procedure in automotive application to measure number concentration and diameter of nanometer sized particles in the size range 10 – 500 nm. This technology has been already satisfactory proved for personal exposure monitors (Asbach, 2012). Since its measuring principle uses electrical charging to count particles, not only it enhances the quality of the global measurement, but also the cost of acquisition and costs per test are significant lower. The instrumentation is compact, easily portable and provides on-line response. Due to these properties it is a suitable technology for particle number concentration measurements in non-laboratory settings. It is battery operated and therefore appropriate for on-board and field measurements.

Experimental results
The latest results, published by JRC during the evaluation of the PEMS-PN measurement technology on behalf of the European Commission (Riccobono, 2014), highlighted the optimal operability of this technology under real driving conditions and the very good correlation of particle number in comparison with PMP Benchmark systems on the chassis dynamometer. The second generation of Diffusion Size Classifier sensor has been recently examined by METAS in Switzerland and declared compliant with the required counting efficiency of the Ordinance on Exhaust Measurement Instruments. These results will be discussed in detail at this presentation.

**Czerwinski J. / AFHB Switzerland**

## Non-legislated Emissions of a Passenger Car with Ethanol Blend Fuel E85

An important objective for a sustainable development of individual transportation worldwide is a well-balanced use of alternative fuels.
Several countries have objectives to substitute a part of the energy of traffic by ethanol as the renewable energy source.
The global share of Bioethanol used for transportation is continuously increasing.
Investigations of limited and unregulated emissions of a flex fuel vehicle with gasoline-ethanol blend fuel have been performed in the present work according to the measuring procedures, which were established in the previous research in the Swiss Network (since 90ties).
The investigated fuel contained ethanol (E), in the portion of 85% by volume.
The investigated vehicle represented a newer state of technology and an emission level of Euro 5. The engine works with homogenous GDI concept and with 3-W-catalyst (3WC).
Since there is a special concern about the particle emissions of gasoline cars with direct injection, the nanoparticle counts measurements were systematically performed with SMPS at stationary and with CPC at dynamic operation.
The non-legislated gaseous emissions were tested with FTIR, this with special focus on NH3, N2O and HCHO (Formaldehyde).
The main results to be mentioned are:

- the particle counts emissions are generally significantly reduced with E85,
- in WLTC there is a clear increase of NH3 with E85 and an insignificant tendency of increasing HCHO (below 1 ppm),
- with both fuels (E0 & E85) there are no emissions of N2O.

The present research did not address the durability aspects and the cold startability in extreme conditions.

Keywords: nanoparticles GDI, nanoparticles E85, non-legislated emissions E85, emission factors, ultrafine particles gasoline, ammonia GDI

**Ehteram M. / School of Mechanical Eng. Sharif University**

## A study on nano-solid particle count and gaseous emission of regeneration period for different DPF technologies

In this study, a diffusion particle counter was used to measure the number concentration and average size of solid nanoparticles during regeneration of loaded diesel particle filters. The dilution system and heated line of the counter ensures a complete removal of volatile compounds.
Different DPF technologies including passive catalytic type, Active and passive sintered metal with FBC regeneration, and ceramic/silicon carbide with FBC regeneration were examined for particle emission during regeneration process. The engine was a Euro II certified 12 liter diesel engine. Diesel fuel with sulfur contents of 229 ppm and 7000 ppm were used in several steady state operating points with different filter technologies.
Fig.1 shows a sample result of Nano particle emission during regeneration of a sinter metal DPF.
It can be concluded that although all examined DPF eliminate up to 98% of solid particle in normal condition, but during the regeneration in almost of the implemented technology the number and size of solid Nano particles (below 300 nm) were increased during regeneration of by 3 orders and 250 nm respectively. Comparing to the passive regeneration, in active regeneration system, the increment of emission was occurred in shorter time. Also, due to particle burning, the CO increased up to 2000ppm and 150 ppm, respectively, in active and passive system. In addition, in CRT systems, the CO emission increase from approximately zero up to 25 ppm. Also, implementing fuel with 229 ppm sulfur content in CRT system, leads to $H_2S$ emission during regeneration.
The sulfur content in fuel did not alter the solid particle number and size, however it can increase $SO_2$ and $H_2S$ emission during regeneration. Increasing the temperature by regeneration, caused re-evaporation of accumulated sulfur condensate on the filter surface which then was converted to $SO_2$. The emitted sulfur component can form new volatile nuclei and particles.

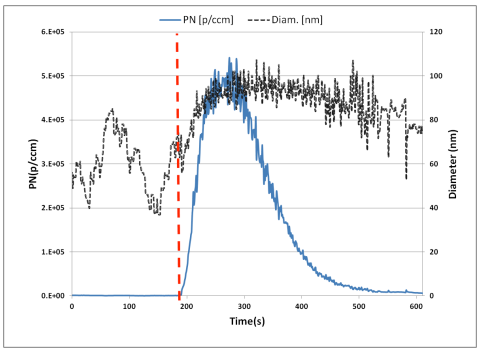


*Fig.1 Particle numbers and average diameter during regeneration test with DPF, (SMF-AR 229 ppm Fuel)*

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**Ess M.N. / Technische Universität München Germany**

## In situ Raman Microspectroscopy of Soot during Temperature Programmed Oxidation since 05/2013:

Soot particles emitted by diesel engines influence human health, environment and climate. To protect environment and people, limits for the emission of diesel particles are set by law. In order to trap the soot particles, cars and trucks are equipped with diesel particle filters (DPF). In a regeneration step, the soot inside the filter is regularly oxidized and consequently removed from the filter. It is known that the reactivity of soot, *i.e.* the temperature at which the soot can be oxidized, depends on the soot's microstructure [1]. Hence, effective tools for the determination of the soot reactivity and its microstructure are necessary to allow a comprehensive soot characterization.
Currently, two very effective tools for soot characterization are temperature-programmed oxidation (TPO) and Raman microspectroscopy (RM). With TPO, soot is burned in a defined environment with a constant temperature ramp and the oxidation products CO and CO2, are quantified by FTIR to determine the reactivity [2]. The spectral parameters of the Raman spectra are connected to the microstructure of the soot [2,3]. The aim of this project is to combine these two powerful individual tools in one setup und follow changes of the soot microstructure *in situ* during heating or oxidation experiments.
Therefore, a cell was developed providing the possibility to perform TPO and RM measurements combined in one setup. A heated steel block allows heating of the cell's inside up to 1000 °C, while the frame is cooled to place the cell under the objective of a Raman microscope and analyse the soot by RM through the quartz glass window. Different possible temperature programs and various gases or gas mixtures provide multiple measurement conditions. Emission products of the oxidation can be quantified by a FTIR device, which is connected to the cell. Soot samples of diverse origin can be deposited on a small plate by thermophoretic precipitation and placed inside the cell.
Different kinds of test soot like spark discharge soot (GfG), propane soot and graphite powder have been analysed by TPO and RM separately in the cell. While GfG soot was heated in inert gas and in air the increase in ordering, means the graphitization, of the GfG soot was followed *in situ* with the Raman microscope. Thereby, structural information dependent on the actual temperature was gained.
The next step is to combine TPO or isothermal oxidation experiments with RM inside the measurement cell by monitoring the emission products by FTIR while following the change in the soot structure by RM *in situ* to get comprehensive results of both methods simultaneously.
Figure: Measurement cell (left) and Raman spectra showing the graphitization of GFG soot during heating (right).
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**Fenkl M. / University of Liberec, Czech Republic**

## Measurement of Emissions from Independent Bus Heaters

Exhaust emissions from independent bus heaters are being investigated in this work. Independent bus heaters studied here combust a suitable fuel to heat the engine coolant to a desired temperature when the engine is not running. They are used not only to preheat the engine itself, resulting in easy start with lower emissions, but also, the hot engine coolant is readily available to provide heat throughout the bus cabin. With the advancement of battery-powered buses, hybrid buses, and other arrangements aimed to reduce energy use and greenhouse gas emissions, the amount waste heat from the engine is declining, and in some cases, might not be sufficient to provide for passenger comfort.

In this work, a diesel powered bus with a diesel power heater, and a compressed natural gas (CNG) powered bus with a CNG powered heater, were tested using a portable, on-board exhaust emissions monitoring system (PEMS). Both buses were newly produced urban transit buses (SOR Libchavy, Czech Republic). Instead of sampling from the tailpipe, PEMS was sampling from the heater exhaust. Concentrations of gaseous pollutants were measured by a hot FTIR (Fourier Transform Infra Red Spectrometer, running at 121 C), while particle concentrations and size distribution were measured by a fast mobility particle sizer (EEPS model 3090, TSI) coupled to a rotating disc microdiluter (dilution ratio 150:1, diluter head at 150 C). The exhaust flow was not measured; rather, the instantaneous fuel flow was measured by feeding the heaters from a separate diesel or composite CNG tank, placed on a high resolution scale. The tests were performed in the morning at 2-3 C ambient temperature.

The particle concentrations in the heater exhaust ranged from not distinguishable from instrument noise (corrected for dilution, about 10^5 particles per $cm^3$) to approximately 10^6 #/$cm^3$ during the diesel heater startup, dominated by the accumulation mode; the particle concentrations on the CNG powered heater were not readily distinguishable from the instrument noise. The gaseous emissions were approximately (diesel/CNG) 1 and 4 g NO, 1 g $NO_2$, 1.5 and 3 g CO per kg of fuel, with spikes of methane at the beginning and end of the each heater operation period.

Buses and technical support provided by their manufacturer SOR, Libchavy, Czech Republic. Measurements funded by EU LIFE+ program, project LIFE10 ENV/CZ/651 – MEDETOX, Innovative methods for monitoring diesel exhaust toxicity under realistic urban operating conditions. M.V. acknowledges support from the European Social Fund project “Support of inter-sectoral mobility and quality enhancement of research teams at the Czech Technical University in Prague” (CZ.1.07/2.3.00/30.0034).

**Fierz M. / / Northwestern University, Switzerland**

## Mobile vs. Static Sensor Networks for Urban Air Quality Assessment

In a collaboration between ETHZ, FHNW and EMPA a mobile monitoring network was operated on streetcars in Zürich in the period of 2012-2014. Mobile monitoring networks offer a much higher spatial coverage than traditional monitoring at fixed stations, however, this comes at the price of lower temporal resolution, as each "site" (here defined as a one-hectare cell of Zürich) is only monitored a few dozen times per day typically. Furthermore, and potentially more seriously, the sensor-equipped streetcars can switch lines between different days, which leads to a very irregular coverage of the city. The data collection is thus rather stochastic in nature, which leads to difficulties in the data analysis, since no complete time series are available for each cell. We will present possible ways of overcoming these difficulties, by adjusting data for temporal coverage and for meteorological variations.
The analysis shows that raw data has to be corrected by about 10% due to the stochastic data collection, and also shows drawbacks of the mobile networks. We can also note systematic effects, such as fewer data points collected on Sundays, when fewer streetcars are operated. Since Sundays typically have lower air pollution due to lower traffic intensity, this leads to a systematic bias in the streetcar network.
The corrected data can be used for modelling of ultrafine particle (UFP) concentrations (number, or lung-deposited surface area) with the use of land use regression. In land use regression, predictor variables such as traffic intensity, building density, elevation etc. are used to create a fit to the experimental data. It turns out that the land-use regression models cannot predict the measured UFP concentrations very well (only roughly 1/3 of the deviations from the mean can be explained). It appears that some information in the input for the model is missing. Looking at the areas where models and experiment disagree, possible missing inputs are data on traffic jams and street canyons.
In general, the models clearly underestimate the variability of UFP concentrations. This affects their usefulness in applications such as epidemiology or the prediction of health-optimal paths between two points in the city.

**Fuć P. / Poznan University, Poland**

## Engine Test Bay Comparison of an Experimental $Ti_2O_4$-based Particulate Matter Filter Support with the Commercially Available Supports

The paper presents comparative investigations of an experimental catalytic support covered with $Ti_4O_7$. The SiC support was assumed as a base on which a metallic layer was applied. The active layer was the catalytic combination of $TiO_2$-$RuO_2$ in the form of nanospheres made with flame spray pyrolysis. Nanopowders for the production of nano-crystallites were obtained using diffusion burners of own design that ensured flame swirls, extended heat zone and even temperature distribution in the flame structure (compared to the temperature distribution in a traditional burner).
An AVL 104/8 SL test stand fitted with a diesel engine of V = 1.3 $dm^3$ was used for the tests. The tested catalytic systems were fitted in the exhaust system at the same distance from the exhaust manifold.
Engine measurement points at steady states, loads of 0, 40, 60, 80 Nm and engine speed of 2000 rpm were assumed in order to validate the experimental catalytic system. The experimental catalytic system has also been tested under actual conditions of operation. A diesel engine was used for the tests. Due to the factory configuration of the engine control, including the filter regeneration procedure, two catalytic systems were selected for tests: reference and experimental. The volumes of the systems were selected according to their exhaust gas flow resistance as a parameter that determines the initiation of the active regeneration procedure. For both tested systems, a route was selected of parameters close to those of the homologation procedure. In order to preserve similar conditions of operation of the tested systems, two test runs, one after another have been carried out under the same traffic conditions. Both catalytic systems, at the time of test initiation were PM free.
In order to compare the catalytic systems, a measurement was carried out of the concentrations of HC, NO, $NO_2$, CO and the concentration and size distribution of PM (concentration and size distribution of PM were measured with Semtech DS and engine exhaust particulate sizer). The exhaust gas was taken from the exhaust gas flow meter on the engine test bed.
The most frequently applied diesel oxidation catalyst + diesel particulate filter were treated as reference systems.

**Fuchsig H. / WMA University Vienna, Austria**

## World Medical Association Calls for Action against Diesel Soot

The abstracts for papers and posters must contain unpublished information on your research subject: background, investigation methods, results and conclusions. Graphs and references are very welcome. Acronyms should be avoided. Abstracts with < 300 words can not be considered. General information on products which are already commercially available can not be accepted as presentations for the conference but are very welcome at the exhibition. Please note, that submission of an abstract includes your agreement to publish your contribution as part of the proceedings of the conference.
At the 65th General Assembly of the World Medical Association (WMA) in Durban, SA (10-11-2014) there has been unanimously adopted the resolution.
At the 65th General Assembly of the World Medical Association (WMA) in Durban, SA (10-11-2014) there has been unanimously adopted the resolution.
**"WMA Statement on the Prevention of Air Pollution due to Vehicle Emissions"**.
The World Medical Association (WMA) as the Confederation of National Medical Associations which are the legal representations of the medical profession in their respective countries regards it as important mission to serve humanity by endeavouring to improve public health. The WMA represents some 10 million physicians all over the world, its secretariat is in Geneva-Ferney close to WHO. The yearly General Assembly is the highest ranking body of decision, the statement, a resolution indeed, calling member organisations to request specific action of their respective governments as below:

1. Introduce Best available technology (BAT) standards for all new diesel vehicles (both, on-road and off-road)
2. Incentivise retrofitting with BAT filters for all in-use engines
3. Monitor and limitthe concentration of nanosize soot particles in urban breathing air.
4. Conduct epidemiological studies dedecting and differentiating the health effects of ultrafine particles.
5. Build professional and public awareness of the importance of diesel soot and the existing methods of eliminating particles.
6. Contribute to developing strategies to protect people from soot particles in aircraft passenger cabins, trains, homes and the general environment. These strategies should include plans to develop and increase use of public transportation.

According to estimates by WHO (2014) urban air pollution including pollution in vehicle cabins is responsible 3.7million death per year (i.e. 6.7% of all) Especially, diesel soot is a proven carcinogenic (IARC 10-2013). Furthermore, it exhibits a lot of toxic effects, most of them in the cardiovascular system (Brooks et al. 2010) and respiratory system (ERS 2010). On top of it, soot as well as methane, both are acknowledged as extraordinary greenhouse drivers per unit mass 500.000 time $CO_2$. In Science (1/2012) Kerr appealed to reduce them urgently.
In addition to air pollution causing a reduction of quality of live for more than 100 million people WMA emphasis a tremendous economic loss on macroeconomic scale due to reduced productivity and increased costs of health treatments.
Despite new and strict regulations in a variety of countries based on limitation of ultrafine particles by number count, a large fleet of in-use vehicles, on-road and off-road ones, construction equipment and ship diesel engines will continue polluting the air unless retrofit is forced. In many regions concentrations of particulate matter are exceeding WHO recommendation by the factor 50. Government induced retrofit is a necessity for improving air quality and consequently health of the population within reasonable time. About 85 million diesel engine are equipped with particle filters of highest standards, a major part by retrofit; benefit is about times exceeding costs, however, the obstacle is in many cases: Who reaps benefit and who is carrying the burden of costs? **It is incumbent on governments to find the appropriate ways and means.**

**Goudeli E. / ETH ZURICH Switzerland**

## The Effect of Sampler Design on Nanoparticles Sizing at High Temperatures

The transport and optical properties of aerosol particles formed at high temperature residence time processes depend on their composition, size and morphology that affect the final product performance. However, particle characteristics like size and structure depend on the design and sampling of the dilution system (Burtscher, 2005) and often change due to coagulation and/or fragmentation in the sampling lines.

Here, the effect of different sampler designs (straight-tube and hole-in-a-tube of varying hole diameter and hole orientation), sampling and diluting hot, highly concentrated flame-made $ZrO_2$ nanoparticles, on their real-time characterization is investigated for the first time. Online, real-time measurements by differential mobility analyzer (DMA) are used to study the growth of airborne particles. The results are compared to the Sauter mean primary particle diameter and geometric standard deviation calculated by counting transmission electron microscopy images obtained by thermophoretic sampling at the flame centerline at 10 – 60 cm height above the burner (HAB). The geometric standard deviation, $\sigma_g$, of the mobility radius at high HAB and fuel-rich flame conditions approaches the self-preserving $\sigma_g$ of about 1.75 as obtained by mesoscale simulations in the continuum regime (Goudeli *et al.*, 2015).

The hole orientation of the hole-in-a-tube samplers affects the measured mobility diameters, especially for low HAB (10 – 40 cm), while the straight-tube sampler results in smaller mobility diameters for both fuel-rich and fuel-lean spray flames. The mobility size distributions of $ZrO_2$ particles are compared to those obtained in the continuum regime by Discrete Element Modeling (DEM) method for spheres and agglomerates. At high HAB particles attain the self-preserving size distribution (SPSD) by coagulation of agglomerates made by diffusion-limited cluster-cluster agglomeration.

Combined DMA and aerosol particle mass (APM) measurements are used to determine the mass-mobility exponent, $D_{fm}$, and average primary particle diameter by a power law correlation between particle mass and mobility diameter. The results are compared to the DEM-obtained $D_{fm}$ and experimental measurements for $ZrO_2$ (Eggersdorfer *et al.*, 2012) and Cu nanoparticles (Stein *et al.*, 2013). The $D_{fm}$ evolution from spherical to fractal-like aerosols is quantified by simple relationships in terms of the number of primary particles per agglomerate that can be used in industrial process design for manufacturing of nanoparticles and air pollution modelling.

Burtscher, H. (2005) *J. Aerosol Sci.*, **36**, 896-932.
Eggersdorfer, M.L., Gröhn, A.J., Sorensen, C.M., McMurry, P.H., and Pratsinis, S.E. (2012) *J. Colloid. Interf. Sci.* **387**, 12-23.
Goudeli, E., Eggersdorfer, M.L., and Pratsinis, S.E. (2015) *Langmuir* **31**, 1320-1327.
Stein, M., Kiesler, D, and Kruis, E.F. (2013) *Aerosol Sci. Technol.* **47**, 1276-1284.

**Goudeli E. / ETH ZURICH Switzerland**

## Coagulation – Agglomeration of Fractal-like Particles

Agglomeration refers to the formation of physically attached primary particles by coagulation and is encountered especially at low temperature processes where particle sintering or coalescence is rather slow. Understanding agglomeration is essential for optimal industrial process design, meteorology and climate dynamics.

Here, the growth and detailed structure of particles undergoing agglomeration are investigated from the free molecular to the continuum regime by discrete element modeling (DEM). Particles coagulating in the free molecular regime follow ballistic trajectories described by an event-driven method, whereas in the near-continuum (gas-slip) and continuum regimes, Langevin dynamics describe their diffusive motion. Agglomerates containing about 10–30 primary particles, on the average, attain their asymptotic fractal dimension, $D_f$, of 1.91 or 1.78 by ballistic or diffusion-limited cluster–cluster agglomeration, corresponding to coagulation in the free molecular or continuum regimes, respectively (Figure 1). A correlation is proposed for the asymptotic evolution of agglomerate $D_f$ as a function of the average number of constituent primary particles, $\overline{n}_p$ that can be readily used in process design for synthesis of nanomaterials or in environmental models for ambient aerosols (e.g. air pollution and climate forcing).

Agglomerates exhibit considerably broader self-preserving size distribution (SPSD) by coagulation than spherical particles: the number-based geometric standard deviations of the SPSD agglomerate radius of gyration in the free molecular and continuum regimes are 2.27 and 1.95, respectively, compared to ~1.45 for spheres. In the transition regime, agglomerates exhibit a quasi-SPSD whose geometric standard deviation passes through a minimum at Knudsen number $Kn \approx 0.2$. In contrast, the asymptotic $D_f$ shifts linearly from 1.91 in the free molecular regime to 1.78 in the continuum regime. Population balance models using the radius of gyration as collision radius underestimate (up to about 80%) the small tail of the SPSD and slightly overpredict the overall agglomerate coagulation rate, as they do not account for cluster interpenetration during coagulation. In the continuum regime, when a recently developed agglomeration rate is used in population balance equations, the resulting SPSD is in excellent agreement with that obtained by DEM.

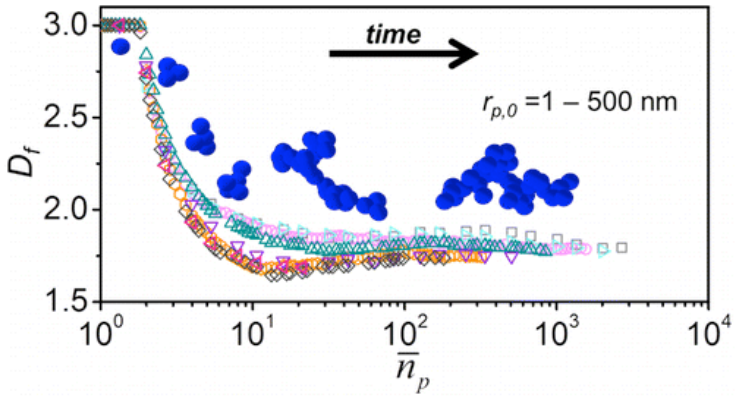


Figure 1. Evolution of DEM-derived fractal dimension, $D_f$, of coagulating agglomerates as a function of the average number of primary particles per agglomerate, $n_p$.

**Hagen D. / Missouri University USA**

## Influence of Ambient Temperature on Gas Turbine Emissions

Air traffic around airports has generated environmental concern since engine emissions can impact local air quality as well as general atmospheric chemistry and climate. An accurate assessment requires that the physical properties, e.g. number and concentrations, of the Particulate Matter (PM) within the exhaust as it exits the engine, along with its evolution in the aging plumes, be understood and well characterized. The Society of Automotive Engineers (SAE) Aircraft Exhaust Emissions Measurement Committee (E-31) has published an Aerospace Information Report (AIR) 6241 detailing the sampling system for the measurement of non-volatile particulate matter (nvPM) from aircraft engines (SAE 2013). An AIR6241-compliant nvPM measurement system – The North American Reference System has been built and evaluated under the joint sponsorship of the FAA, EPA and Transport Canada. This measurement system was used in an emissions measurement campaign conducted at the Honeywell San Tan Remote facility on a mixed flow gas turbine engine mounted in a test stand and burning JetA fuel. nvPM emissions measurements were made over a four day period during July/August 2014. The engine was operated at several power levels. PM emissions were captured in two Honeywell sampling probes, one positioned in the core flow and one downstream of the engine exit plane sampling the mixed flow exhaust. The sample was split and delivered to the Honeywell and Missouri University of Science and Technology (MS&T) instrument trailers. Number and mass based PM emission indices and size distributions were measured.

One of the main objectives of the campaign was to investigate the effect of changing test condition variables such as engine power and ambient temperature. Large ambient temperature variations (~13 C) were observed during the campaign, especially between the early morning and late afternoon test periods. This paper summarizes and describes the results of the campaign, in terms of the influence of ambient temperature and power on total PM emissions at both sampling locations. The MS&T data was used in this analysis.

RESULTS. Statistically significant changes in emissions were observed with respect to engine power and ambient temperature. For number the difference was smaller when corrected for thermophoretic loss, but not so for mass. The ambient temperature dependence was stronger at high engine power conditions as compared to low and mid power. Emission indices and mean size were more sensitive (per degree) to ambient temperature than power, although the range of power was far wider than for ambient temperature. In general a statistically meaningful difference was observed between core and mixed samples at the engine exit plane. For lower power, the mixed emission indices tend to converge to the core values at higher ambient temperature. For higher power, the mixed and core emission indices exhibit similar slopes with respect to ambient temperature.

**Hagino Hiroyuki / JARI Japan**

## Brake Wear Particles Emissions using a Dynamometer System under Driving Cycles

A brake wear dynamometer with a constant-volume sampling system was developed to measure driving distance-based mass emission factors of airborne brake wear particulate matter (PM). Brake wear particle emission factors from non-asbestos organic (NAO) friction material (pads and lining) used in brake assemblies were determined for two passenger cars and one middle-class truck under transient driving cycles using the tailpipe emission test method. Real-time monitoring revealed brake wear particle emissions at deceleration when braking force was applied, but also at acceleration, which likely resulted from resuspension of particles from the surfaces of brakes and grooves. The levels of observed airborne brake wear particle emissions for $PM_{2.5}$ was sub-mg/km/vehicle. Airborne brake wear particles originating from less than 21% of the mass of wear of brake pads or linings, it is indicated that not all brake wear debris becomes airborne particles. Carbonaceous components, which included organic carbon, elemental carbon, and semivolatile carbon fractions increased in airborne PM compared with the original friction material. Radioactive carbon isotopes were also used to determine the percent modern carbon (pMC) of brake wear particles as $PM_{2.5}$ (pMC of 20 or less), which indicated that isotopic changes occurred during the abrasion process. Organics components were found in the non-refractory submicron particle phase using time of flight aerosol mass spectrometer (ToF-AMS) under normal in-use 600 °C detection, indicating that they originated from organics in the NAO friction materials. Although the organics from brake dust are primary organic aerosols (POAs), the higher oxidative components observed, compared with the NAO brake materials and tailpipe emissions, show that there are similar oxidation levels of secondary organic aerosols (SOAs) and ambient water soluble organic aerosols as oxygenated components. This indicates the possibility of NAO friction particles changing to oxygenated organic particles during the abrasion process. Lastly, key tracers of brake dust (e.g., Fe, Cu, Ba, and Sb) were identified during this study at comparable emission levels with traffic-related ambient PM. In other words, it is suggested that the mg/km/vehicle emissions in the brake dynamometer tests are capable of being detected in traffic-related ambient PM.

**Hama S.M.L. / University of Leicester UK**

## Monitoring of Ultrafine Particle Number Concentration and other Traffic- related Air Pollutants at one Urban Background in Leicester, over the Course of a Year

Within the Joaquin project, ultrafine particles (UFP, particles <100 nm) are continuously measured at one urban background in Leicester city, UK. The main aims are to investigate the seasonal and temporal variations in UFP number concentration and size distribution, and also to show correlation between UFP and other traffic-related air pollutants.

The study presents the results from an experimental investigation into the particle number concentration size distribution of UFPs, BC and NOx with measurements taken at the Automatic Urban and Rural Network (AURN) monitoring site in Leicester. The monitoring was performed as part of the EU project JOAQUIN (Joint Air Quality Initiative; www.joaquin.eu) supported by the INTERREG IVB NWE programme. The total number concentrations (TNC) were measured by a water-based condensation particle counter (W-CPC) (TSI model 3783), the particle number concentrations (PNC) and size distributions were measured by an ultrafine particle monitor (UFP TSI model 3031), the BC by MAAP (Thermo-5012), and the $NO_X$ by NO-$NO_2$-$NO_x$ monitor (Thermos Scientific 42i) between December 2013 and November 2014. From the results showed in table 1 it can be argued that the general seasonal variation observed. This difference for PNC, as well as for BC and $NO_X$, was found more obvious during the cooler season than the warmer months.

Table. Average concentrations of $N_{UFP}$ (20-100nm) and $N_{ACCU}$(100-500nm)(#/cm$^3$), BC and $NO_x$ (µg/m$^3$) Dec13-Nov14.

| Season | $N_{UFP}(N_{ACCU})$ (#/cm$^3$)*10$^3$ | BC($NO_x$) (µg/m$^3$) |
|---|---|---|
| Winter | 5.7(1.04) | 1.44(38.3) |
| Summer | 5.2(0.86) | 1.13(25.8) |
| Spring | 5.4(1.25) | 1.37(37.35) |
| Fall | 5.45(1.24) | 1.81(40.97) |

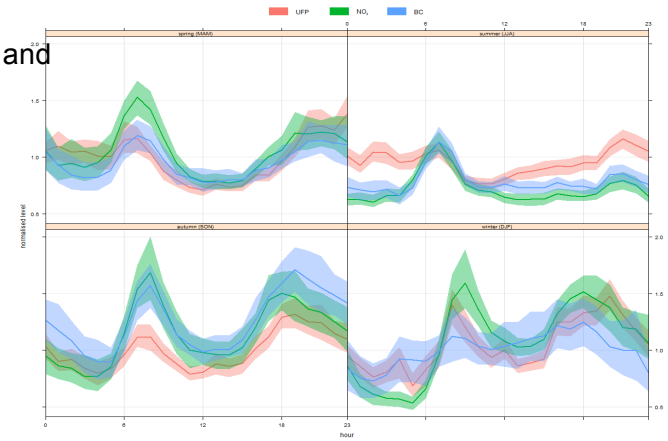


Figure 1: Seasonal variation plot for UFP (*10$^2$), BC and $NO_X$ at AURN Leicester (Dec13-Nov14).

The effects of meteorological conditions, particularly wind speed and direction, and also temperature on the observed distribution of ultrafine particles will be detailed.
In general, PNC levels were highest in winter , Spring and fall and lowest in summer (figure 1), higher on weekdays and Saturdays compared to Sundays, and higher during morning rush hour compared to later in the day. During the cool season the morning and evening UFP peaks at rush hours can be considered the result of the motor vehicle emissions combined with a lower mixing layer height and lower temperature. The morning peak still present in summer months, but with lower absolute values of UFP than in winter and fall, might be related mainly to particles directly emitted by traffic and to the more favourable conditions of atmospheric dispersion. Overall, the results highlight the importance of the atmospheric particles pollution originating from road traffic and domestic heating (especially in winter and fall) in Leicester and a clear seasonal variation was observed, with higher values during the cooler season.

**Heeb N. / EMPA Switzerland**

## PCDD/F Formation in active DPFs: the Inconvenient truth about Biofuels

**Abstract:** Particle filters (PF) have evolved to an efficient and reliable environmental technology to abate particle emissions of diesel engines. They are increasingly tested on gasoline direct injection vehicles (GDI) as well. PFs are considered as best available technology (BAT) to detoxify diesel exhaust (DE) which has been rated as class 1 carcinogen by the WHO in 2012.

Since 2009, the Swiss clean air act (LRV) includes a particle number (PN) emission limit of $1x10^{12}$ particles/kWh for construction machinery. This limit can also be applied for stationary diesel engines which currently are not regulated with respect to their PN emissions. Environmentally safe filters should also reduce emissions of genotoxic compounds. This does also imply that no additional genotoxic compounds should form in filters (no toxic secondary emissions). Among the most prominent genotoxic compounds found in DE are certain polycyclic aromatic hydrocarbons (PAHs) and their nitrated forms (nitro-PAHs). These compounds are responsible for most of the genotoxic potential of DE. It has been shown that many PAHs are efficiently removed by VERT approved filters and a secondary formation of nitro-PAHs can be minimized with catalyzed filters [1,2].

In cells, these compounds preferentially bind to the aryl hydrocarbon receptor (AHR) and translocate to the cell nucleus where they, after metabolic activation, can bind to DNA. We have shown that DE indeed contains various AHR ligands and proved that iron- and copper-catalyzed filters remove about 80% of these AHR ligands [3].

Polychlorinated dibenzodioxins/furans (PCDD/Fs) are aromatic compounds as well. They also bind to the AHR. In fact, the strongest AHR ligand known today is 2,3,7,8-TCDD. Viktor Yushchenko, the former President of Ukraine, developed severe health problems after being poisoned with 2,3,7,8-TCDD during his re-election campaign in 2004 [4].

An assessment of the PCDD/F forming potential of PFs is an integral part of the VERT filter test also described in SN 277206. It has been shown that certain copper-based fuel borne catalysts (FBCs) support a de novo formation of PCDD/Fs in filters [5]. Recently, a first non-copper DPF was found that also catalyzed a PCDD/F formation [6]. This filter was operated in combination with an iron/potassium-based FBC. Because all iron-only filters tested (n=11) so far did not support a PCDD/F formation, we concluded that potassium not iron must have a promoting effect [6].

Iron-based DPFs are widely used in Europe and millions of vehicles are operated on our roads today. When realizing that biofuels, now frequently used as well, may contain up to 5 mg/g potassium according to current fuel specifications, we hypothesized that the combustion of biofuels may alter the PCDD/F formation potential of so far inactive iron-catalyzed DPFs.

In the presented paper, we will compare PCDD/F emissions of three different iron-catalyzed DPF systems and discuss in detail the characteristic pattern changes observed when an inactive system is transformed to an active one. These patterns are unique and can be considered as good indicators to assess the PCDD/F forming potential of filters. As a consequence of the presented data we conclude that the Swiss clean air act has to be adopted. Instead of an explicit ban of copper-catalyzed filters it should exclude all filters actively supporting a PCDD/F formation, including the active Fe/K system. Furthermore, we conclude that the PCDD/F forming potential of all iron-catalyzed filters which will be in contact with potassium containing biofuels should be carefully tested.

**Heijari J. / Neste Oil**

## Sulphuric acid and aerosol particle production in the vicinity of oil refinery

We introduce new in-situ observations of trace gases, aerosol particles and their precursors in the vicinity of oil refinery and industrial area in Kilpilahti, Southern Finland. We conducted one month measurement campaign near the oil refinery during summertime when the sulphur dioxide concentrations on the site are typically the highest. The source areas around the measurement station were divided into three sectors: oil refinery area, industrial area and non-industrial area. According to the results, all the measured concentrations expressed great variation between source areas. The median sulphur dioxide concentrations for oil refinery, industrial and non-industrial area were 1.88 ppbv, 0.75 ppbv and 0.38 ppbv, respectively. The corresponding concentrations of sulphuric acid were $11.5 \cdot 10^6$ molecules/cm$^3$, $4.37 \cdot 10^6$ molecules/cm$^3$ and $1.28 \cdot 10^6$ molecules/cm$^3$. The observed concentrations were at the same range that has been measured in urban or industrial sites. The median ratio between sulphuric acid and sulphur dioxide was $3.6 \cdot 10^{-4}$ being higher when the air mass was coming from oil refinery. Correlation between sulphuric acid and 1-2 nm particles was significant but the composition of the particles remained unknown since no neutral clusters were detected with the mass spectrometer. Only a few new particle events were observed during the measurement period and a great part of their growth was explained by sulphuric acid.

**Hess A. / PSI Switzerland**

## Particulate Metal Emissions from Wood Incineration Measured Online Using RDD-SMPS-ICPMS

In the last years we presented a hyphenated setup consisting of Rotating Disk Diluter (RDD), Scanning Mobility Particle Sizer (SMPS), and Inductively Coupled Plasma Mass Spectrometry (ICPMS), which allows the online determination of the size resolved elemental composition of air borne particles in the sub-micrometer size range. Traditional offline methods entail the risk of contamination or other alterations during particle sampling, storage, and preparation for analysis. These drawbacks can be overcome using RDD-SMPS-ICPMS, and at the same time, SMPS typical measuring time resolutions of a few minutes can be achieved.

This setup was now coupled to a thermo-gravimeter (TG), which allows correlating size resolved measuring data to incineration temperatures. This year we would like to present actual size and temperature resolved measuring data on particulate metals, emitted by lab scale wood incineration, determined by TG-RDD-SMPS-ICPMS.

**Hueglin C. / EMPA Switzerland**

## Trend and Spatial Variability of Ambient Ultrafine Particle Concentration in Switzerland

Health effects studies imply that exposure to ultrafine particles (UFP) can impair human health through mechanisms other than those of larger particles that dominate the mass concentration of atmospheric particulate matter (e.g. PM2.5 and PM10). Although there are no air quality standards for UFP, there are therefore good reasons to observe ultrafine particle concentrations in order to achieve a better understanding of the temporal trend, the spatial variability and the associations with other air pollutants.

Within the Swiss national air pollution monitoring network ultrafine particle number concentrations (PNC) have been measured for more than ten years using condensation particle counters (CPCs). These measurements are performed at sites that are representative for typical air pollution situations, ranging from urban traffic sites to suburban and rural locations. We present comprehensive analyses of the available long-term time series and discuss the trend of UFP concentrations in Switzerland, the relationship between PNC and other air pollutants, as well as the gradient in UFP concentrations between urban, suburban and rural locations. The urban increment for ultrafine particle concentration is higher than for many other air pollutants. The large impact of traffic on PNC in Switzerland results in the highest concentration levels at heavily trafficked sites. PNC is about ten times smaller at rural and elevated sites.

Complementary to the long-term observation, the intra-urban variability of UFP concentrations in the city of Zurich was assessed. This assessment is based on campaign measurements at several urban sites and on data from a mobile measurement network. The instruments of this network were installed on the roof of streetcars which were operating in the city on a regular schedule. The measurements reveal the largest intra-urban differences in PNC occurring during the morning rush hour related to the high traffic volume and meteorological conditions. Interestingly, the intra-urban variability of UFP number concentrations almost disappears during the night, when traffic and other human activities are lowest.

Finally, we present results of the differentiation of total and non-volatile UFP number concentrations. The corresponding measurements were performed during more than one year at a rural roadside location next to a motorway with heavy traffic. Parallel to total UFP concentrations measured with a CPC, a thermo-denuder (TD) operated at 400°C upstream of a second CPC has been used for detection of non-volatile particles. It is clear from these measurements that a large fraction of ultrafine particles released by road traffic vehicles into the atmosphere can be volatilized. We will present a summary of the volatile fraction of ultrafine particles depending on factors such as daytime, weekday, season and wind direction (upwind or downwind of the nearby motorway).

**Jang Jinyoung / Korea Institute of Energy Research**

## Emission Characteristics by DPF Regeneration and Ash Contents in 1.6 L CRDI Diesel Vehicle

In a Diesel vehicle, PM and PN are hot issue as well in GDI vehicle because of emission regulation. Therefore, newly developed Diesel vehicle is equipped DPF system. All of these vehicle should do DPF regeneration to decrease back pressure by loaded PM in DPF channel. However, Ash remains in DPF and slowly increases the back pressure. It is reason why DPF replacement is needed in higher mileage diesel vehicle.

In this study, we evaluate the emission comparing old DPF and new DPF, and with and without DPF regeneration. And also Ash contents were analyzed. For this study, 1.6 L CRDI diesel vehicle equipped with DPF system was used. Just before this study, vehicle mileage was 167,068 km. Test mode is idle state, 90 km constant speed and FTP-75. AVL i60 and FTIR(SESAM 2030, AVL) were used for the regulated and unregulated emissions respectively. The number of particles from vehicle was measured by PPS-m system. PM and ash contents was analyzed by SEM-EDS and XRF analyzer. The length of loaded ash was measured by x-CT that was a nondestructive inspection and the portable microscope.

The PN, THC, NOx and CO2 emissions and fuel consumption during DPF regeneration were higher than without those at DPF regeneration state. Especially, PN increased over 10^5 times. The THC, CO and NOx and fuel consumption with new DPF was lower than those with old DPF because of the catalytic activity. The length of loaded ash inside DPF measured by x-CT was shorter than that of direct measurement. The shape of ash observed by microscope looks like piles of sand. Ash Over 50% of Ash is composed of Zn, Ca and P elements that were main lubricant's additives. Soot were coexist with ash at inlet area of DPF. From inner space to DPF's wall, C element and additive elements of lubricant was detected by SEM-EDS.

**Järvinen A. / Tempere University Finland**

## Portable Emission Measurement System (PEMS) for Exhaust Aerosols

Portable emission measurement systems (PEMS) have been typically used to analyze vehicle gaseous emissions or particle mass in real-world driving conditions. The commercially available PEMS have been mostly concentrated on measurement of gaseous emissions. The particle measurement capabilities of these systems have been typically designed according to standards and thus rather fixed to certain technologies.

We have developed a PEMS especially for exhaust particle measurements, which can be tuned for different measurement setups. For the direct tailpipe sampling and dilution of exhaust, two basic setups have been developed; either two stage ejector sampling with a heating option or porous tube type dilution followed by an ejector dilutor may be used. In both cases the dilution takes place immediately after the sampling of raw exhaust so that the diluters are located outside of the vehicle, in close proximity to the exhaust pipe outlet. In addition, the system allows the exhaust sampling from the exhaust plume after the first steps of natural dilution of the exhaust in the atmosphere. Thus, in addition to measurements of regulated pollutants, the system makes it possible to study the emissions of nucleation particle emission of vehicles, which are practically not regulated but, however, observed to exist in real exhaust (e.g. Rönkkö et al 2006) and urban atmosphere near traffic. The dilutors are installed into a rail, which is installed into the towing hook of the vehicle. The developed PEMS requires no modifications on the vehicle itself.

The diluted sample is brought to aerosol instruments inside the vehicle by flexible tubing. The actual PEMS unit consists of a 2.4 kWh lithium iron phosphate battery and a main unit. The main unit provides dried and filtered dilution air for exhaust gas sampling. Modified CO2 sensors (GMM111 and GMM112, Vaisala Oyj) are used to measure the raw and diluted CO2-concentrations in order to calculate the dilution ratio. The main unit also provides power for the instruments by an inverter (PP 2004, Dometic WAECO International GmbH).

The PEMS has been tested on three different vehicles: diesel van with a Diesel Particulate Filter (DPF), diesel passenger car without DPF and gasoline passenger car with a direct fuel injection. In our measurements, real time aerosol instruments have been used to study exhaust particle concentrations and size distributions. Both Condensation Particle Counter (CPC 3776, TSI Inc.) and Engine Exhaust Particle Sizer (EEPS, TSI Inc.) have been used. The PEMS allows also different instruments to be used, for instance an Electrical Low Pressure Impactor (ELPI, Dekati Oy) and PPS-M (Pegasor Oy) have been considered as an alternative instrument option.

The particle emissions from the gasoline vehicle in different driving situations are presented in Figure 1. The constant speed driving in highway (100 km/h) was found to produce fewer emissions than average driving and the particulate emissions were mostly generated during acceleration periods.

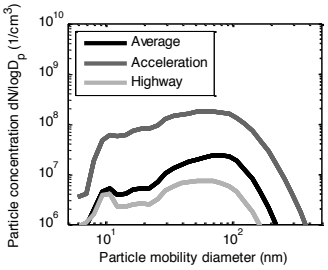


Figure 1. Particle size distributions from the gasoline passenger car in different driving conditions.

**Jin Dongyoung / Korea University**

## Analysis of Aged Diesel Particulate Filter and Ash Components with Physico-chemical Validation

The purpose of this study is for the investigation on the impact of engine oil formulation and aging on MSAT (mobile source air toxic) emissions and PM (particulate matter) characterization from light duty diesel engine and aged DPF (Diesel Particulate Filter) analysis process. It is widely known that lubricant specifications and consumption from an internal combustion engine have significantly influenced on the regulated and unregulated harmful emissions as the engine operating conditions and vehicle mileage accumulations.

As diesel engine has a good fuel economy and torque characteristics, diesel light duty vehicles have taken centre stage. However diesel combustion causes PM formation rather than gasoline combustion. To solve this phenomenon, DPF should be equipped after Euro-5 standard. As DPF equipped vehicle driven for a long time, aged DPF has clogged by ash components.

Considering DPF clogging phenomena with lubricant-derived PM/ash components, simulated aging mode for the DPF was newly designed for engine dynamometer testing. PM/ash accumulation cycle were contrived in reflecting real-world engine operating conditions, such as aggressive transient speed/load change for the increment of engine oil consumption and natural DPF regeneration for the ash accumulation. The test duration for DPF aging reached around 100 hrs with high- and low-SAPS engine oils, respectively. Detailed changing of engine oil specifications, engine performance, and exhaust emissions were evaluated through the test period.

Real-world aged DPF was investigated with physical and chemical characterization on PMs with X-CT, micro-scope optical analysis, SEM, and TEM instruments. Catalytic activity on the exhaust emissions was evaluated with the DPF analysis process. Finally, XRF, XRD and XPS equipment for component and structure analysis were investigated in this study on the ash and clogged substrate. The physiochemical characteristics of the real-world aged DPFs around 140,000 km and 190,000 km were assessed to inspect the soot/ash accumulation characteristics in the DPF channels sites. Especially, engine oil-derived soot/ash components deposited in the DPF substrate showed distinctive characteristics with the formulation of the engine oil additives. Various physiochemical analytic instruments were applied to establish the diesel engine originated PMs and ash components in the DPFs.

**Kato K. / NGK Germany**

## GPF Concepts with Integrated Catalyst for Low Backpressure and Low CO2 Emissions under Real Driving Conditions

In order to meet the challenging $CO_2$ targets beyond 2020 despite keeping high performance engines, Gasoline Direct Injection (GDI) technology usually combined with charged aspiration is expanding in the automotive industry. While providing more efficient powertrains to reduce fuel consumption one side effect of GDI is the increased particle formation during the combustion process. For the first time for GDI from September 2014 there is a Particle Number (PN) limit of 6E12 #/km, which will be further reduced by one order of magnitude to 6E11 #/km effective from September 2017 to be the same level as applied to Diesel engines. In addition to the PN limit of the certification cycle NEDC further certification of Real Driving Emissions (RDE) including portable PN measurements are under discussion by the European Commission. RDE test procedure requires stable and low emissions in a wide range of engine operations and durable over a distance of 160 000 km. To achieve such stringent targets the ceramic wall-flow Gasoline Particulate Filter (GPF) is under discussion as one potential novel emission control device.

There are two main approaches how to implement a GPF into an exhaust system.
– A non-catalyzed GPF can be added downstream of an existing Three Way Catalyst (TWC). While the sole function of this bare GPF is to trap incoming soot particles it can be optimized for filtration efficiency and backpressure.
– Alternatively a catalyzed GPF can either be added downstream of an existing TWC or replace an existing TWC completely. In contrast to the first option this coated GPF combines the particle trapping and the catalytic conversion in one single device. The main parameters to consider when introducing this technology are thus filtration efficiency, backpressure and coatability or catalytic conversion efficiency.

Several tests were conducted mainly focusing on coated GPFs to determine the influence of future EU6 boundary conditions on filtration efficiency (FE) and pressure drop (PD). The following questions were of interest:

Particulate Number and filtration efficiency

– Which influence do low PN raw emissions have on FE?
– Which influence do different low to high engine load driving cycles have on FE?
– Does preconditioning of a GPF have an influence on FE?
– Which change in FE can be expected by changing the filter volume?
– How will FE evolve over mileage due to ash accumulated in the GPF?
– How will the position of the filter relative to the engine exhaust outlet affect FE?

Pressure drop / Influence on $CO_2$ and power output

– How much does a GPF increase system PD under different low to high engine load driving cycles and what is the resulting influence on $CO_2$ emissions?
– How does a GPF influence PD at full load engine running and how does this influence specific fuel consumption?
– How does ash ageing increase the PD and does this affect the $CO_2$ emissions?
– How can the length to diameter ratio (L/D ratio) be optimized to benefit from PD reduction while keeping low PD even after ash accumulation?

**Keller A. / FHNW Switzerland**

## Estimation of the SOA-Formation Potential in Emissions from GDI Engines

In the next decades to come, we will be exposed to exhausts of gasoline direct injection (GDI) vehicles with yet unknown consequences. In the GASOMEP (Current Status and New Concepts of **Ga**soline Vehicle Emission Control for **O**rganic, **Me**tallic and **P**articulate Non-Legislative Pollutants) project, we will investigate the emission characteristics of various GDI vehicles and evaluate the potential of gasoline particle filters (GPFs) currently developed by our industrial partners. The three-year project will result in a comprehensive characterization of GDI vehicle emissions and evaluate the potential of new filter technology to abate potentially harmful exhaust constituents. The project is a joint effort of the industry, regulators, and the Swiss research institutions PSI, the Universities of Applied Sciences and arts Northwestern Switzerland and Biel, and Empa.

Within the framework of GASOMEP, secondary organic aerosol (SOA) forming potentials are being investigated with smog chamber experiments, executed PSI Switzerland, and two independent flow reactor approaches. Here we report first results from one of these reactors, the Micro Smog Chamber. Our approach is different than traditional aging experiments in that we concentrate exclusively on the formation of secondary aerosol by taking the gas-phase fraction of the emissions and oxidize it using ozone concentrations up to 60ppm. The residence time at this high oxidant concentration is of the order of 10 seconds. This reduces the volatility of the organic fraction of the emissions and, in the absence of seed aerosol, results in a nucleation mode formed exclusively of secondary aerosol. The nucleation mode can then be measured by means of a SMPS system during steady state conditions. Our aim is to establish an average size distribution of the secondary emissions generated in our system (e.g. fig. 1) and then use a much faster particle counting technique to establish a real time (seconds resolved) emission factor during transient cycles. The micro smog chamber is up to our knowledge the system with the fastest oxidation of SOA precursors and thus achieves the best time resolution.

This is the first time that the micro smog chamber has been tested with vehicle emissions. Nevertheless, we have a clear signal originating from secondary aerosol. The level of potential secondary emissions per amount of fuel is several orders of magnitude lower than what we have observed in wood burning experiments (our standard test system).

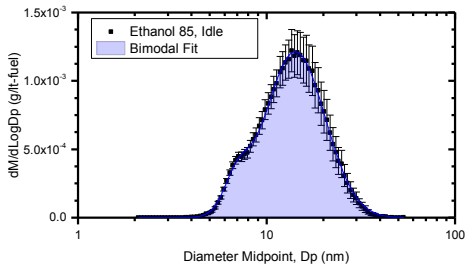


Fig 1. Average mass-weighted particle size distribution (black squares) of the secondary aerosol produced in the micro-smog chamber for the idle cycle of a GDI vehicle using an 85% ethanol - 15% gasoline mixture. Error bars show the standard error of the mean. The integral of the fitted curve (shaded area) can be used to calculate an average emission factor for the secondary aerosol. A particle density of $\rho$=2000 kg/m$^3$ was used for these calculations.

**Khan M.Y. / Cummins USA**

## Characterization of Repeatability and Reproducibility of BSN-Measurements from AVL Particle Counters

The main objective of this study was to quantify repeatability and reproducibility (R&R) of brake-specific particle number (BSPN) measurements by using three AVL Particle Counters (APC) under actual testing conditions. The study was conducted on a single, heavy duty diesel engine (ESN 79192865, model year 2007, model ISX, X2 family) equipped with a diesel oxidation catalyst and a diesel particulate filter. The study was conducted as an extension of an ongoing baseline engine testing program. Particle number measurements were made when baseline engine ran on multiple Federal Testing Procedure (FTP) and the Ramped Modal Cycle (RMC) test cycles in multiple CVS test cells at CTC.
The engine had very large variation in BSPN, which was observed on all three APC instruments (units). This was attributed to variation related to the conditioning of the DPF. Given this variation, it is expected that engine and aftertreatment preconditioning will be a common practice when measuring BSPN. To estimate R&R values representative of the entire test process, including preconditioning, only the second set of hot FTP test cycles in the baseline test plan were used to characterize R&R of BSPN.
The BSPN R&R values are based on nine sets of repeat hot FTPs. Each set of repeat hot FTPs typically had five cycles. The total number of FTP cycles analyzed was 53. Each FTP cycle typically had three observations of BSPN based on three APC units. The total number of BSPN observations analyzed was 149. This data was collected from the period of 68 days in five CVS test cells. The global average of the 149 BSPN observations was 1.3918E+11 #/kW-hr. The global average BSPN was used to calculate relative variation in BSPN for both the entire test process and for the APC units only. BSPN repeatability was 3.5388E+9 #/kW-hr (2.5 % of the global average). BSPN reproducibility was 4.4155E+10 #/kW-hr (31.7 % of the global average). The relative variation (COV) of BSPN among the three APC units varied between 2.6 to 9.6 % on the 43 FTP cycles where data was available from all three units. The repeatability of APC unit was 0.69%. The reproducibility of APC unit was 6.2%.

| **Repeatability** | **#/kW-hr** | **% of Global BSPN** |
|---|---|---|
| BSPN | 3.5388E+09 | 2.54 |
| APC | 9.6150E+08 | 0.69 |
| Test Process | 3.4057E+09 | 2.45 |

**Repeatability of BSPN measurements, APC units, and Test Process**

| **Reproducibility** | **#/kW-hr** | **% of Global BSPN** |
|---|---|---|
| **BSPN** | **4.4155E+10** | **31.7** |
| **APC** | **8.6086E+09** | **6.2** |
| **Test Process** | **4.3308E+10** | **31.1** |

**Reproducibility of BSPN measurements, APC units and Test Process**

Total variation is defined as the sum of the variance of repeatability and reproducibility of BSPN measurements. Based on 149 BSPN measurements from three APC units, variation due to repeatability and reproducibility were found to be 0.6% and 99.4% of total variation, respectively.

| | | | |
|---|---|---|---|
| **Variation due to Repeatability** | **0.06%** | **APC** | **0.05%** |
| | | **Test Process** | **0.59%** |
| **Variation due to Reproducibility** | **99.4%** | **APC** | **3.8%** |
| | | **Test Process** | **95.6%** |
| **Total Variation** | **100%** | | |

**Variation in BSPN measurements due to repeatability and reproducibility**

**Kilic D. / PSI Switzerland**

## Characterization of On Methane Volatile Organic Compound Emissions from Aircraft Turbine Engines

Aircraft account for 3% of the total fossil fuel consumption each year [1]. Their emissions include non-methane volatile organic compounds (NMVOCs), which have been linked to cancer in animal experiments and epidemiological studies [2-4]. NMVOC emissions from in-service aircraft turbine engines were investigated using a proton transfer reaction time-of-flight mass spectrometer (PTR-ToF) at the SR Technics engine test facility at Zurich Airport. Experiments consisted of 52 engine exit plane measurements for 7 engine types under simulated flight conditions for operations at an airport, i.e., engine thrust typical of idling, approach, climb, and take-off. Measurements were conducted in the test cell where the routine engine maintenance and safety checks are performed. Sampling was performed from a probe located in about 50 cm distance to the engine exit plane. Other gas phase emissions such as CO, $CO_2$, $NO_X$, $CH_4$, total hydrocarbon (THC) were also measured in order to estimate emission indices (EIs) of NMVOCs for each flight mode and engine type. EIs for more than 200 compounds were calculated by using PTR-ToF data - and the relative contributions of functional groups - e.g., acids, carbonyls, aromatics, aliphatics – were calculated in order to monitor the exhaust chemical composition at each flight mode. In agreement with former studies [5-7], NMVOC emissions were highest at idling when the engine thrust level was lowest and decreased with increasing thrust (lowest average NMVOC during climb). Most previous studies used passive sampling measurements and/or were limited to few selected compounds to characterize the aircraft VOC emissions. Here we cover many more compounds and also classify them by functionality. Our analyses show that the relative contribution of pure hydrocarbons (particularly aromatics and aliphatics) of the jet engine exhaust decreases with increasing thrust while the fraction of oxidized VOCs (acids and carbonyls) increases. The engine thrust rating (maximum force generated) may also effect the chemical composition of the NMVOC emissions during idling. Engines with higher thrust rating emitted a higher fraction of non-oxidized VOCs compared to those with lower thrust rating.

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**Kittelson D. / University of Minnesota, USA**

## Ultrafine and nanoparticle measurements in jet aircraft exhaust

The International Civil Aviation Organization is in the process of developing new methodology and standards for the measurement of particle emissions from aircraft gas turbine engines. Solid particle mass and solid number larger than 10 nm diameter are to be measured and regulated although not all countries will regulate number. Exhaust sampling from such engines is extremely challenging because of the high temperature, velocity, and volume of exhaust. In a normal regulatory test, it is not possible to put measurement instruments near the exhaust plane of the engine. Consequently, very long sampling lines are to be used, approximately 33 m in the proposed measurement system. The exhaust particles are very small, typically 15 to 30 nm geometric mean diameter and these long lines result in significant size dependent particle losses, especially by diffusion, typically more than a factor of 4 by number and 2 by mass.
In principle, if the dilution and sampling system is well characterized and the exit plane size distribution is known, it should be possible to determine and correct for line losses. In practice, the exit plane size distribution is not known and the only measurements made are solid particle mass and number at the end of the sampling line. Fortunately, exhaust plane size distributions from aircraft engines are typically unimodal and log-normal. Only 3 parameters, concentration, geometric mean diameter, and geometric standard deviation are necessary to describe such distributions. If these parameters are known, total number, surface, volume, etc. can be calculated, and if density is known, mass can also be calculated. The challenge is to link measured mass and number at the end of the sampling line to the size distribution at the engine exit plane, with 4 unknowns and only 2 measurements. The proposed method assumes a geometric standard deviation at the exit plane and a fixed particle density and uses an iterative procedure to determine the exit plane particle size and concentration that will result in the measured mass and number concentrations at the end of the sampling line. Recent experiments are described in which the method was against actual size distribution measurements. Uncertainties are discussed.

**Kiwull B. / Institute of Hydrochemistry, Germany**

## Evaluation of Volatile Particle Remover Devices for Exhaust Particle Quantification

Fine and especially ultrafine particles are considered to be harmful for human health (Oberdörster et al., 1995). As diesel-powered vehicles are a significant source for particles in this size range, it is important to limit and consequently reduce the emissions caused by their exhaust. Unfortunately, the well-tried attempt to confine the emissions based on the particle mass sampled on a filter turned out to be ineffective for ultrafine particles and low particle concentrations (Matter et al., 1999). For this reason a new emission limit which is based on the particle number, was established within the European Union in 2011 (EU 566/2011).
Additionally to the number limit a new measurement procedure was introduced. It suggests a quantification of particles with a condensation nucleus counter with a lower detection limit of 23 nm. It furthermore asks for a removal of volatile particles from the exhaust gas (volatile particle remover, VPR) before quantification of solid particles.
The reason for the application of a VPR is, that volatile exhaust components may form liquid droplets (e.g. $H_2SO_4$) or condense on already present soot particles (e.g. hydrocarbons) depending on temperature and dilution conditions during measurement. Homogeneous or heterogeneous nucleation of volatile components alters particle number concentrations and may also influence counting efficiencies of the condensation nucleus counter that is used for exhaust particle counting. As a consequence not only solid accumulation mode particles but also volatile nucleation mode particles might be counted. This may result in an overestimation of the number of solid accumulation mode particles (Kiwull et al., 2015).
Therefore it is necessary to investigate how efficient volatile particles can be separated from solid ones. For this reason two different VPR were constructed and tested with model aerosols. With sulfuric acid aerosol, it was found out that the constructed catalytic stripper is able to remove up to 99.9 % (number concentration) of an aerosol with a mass concentration (0.8 mg/m$^3$) comparable to concentrations in exhaust gas of high duty diesel engines (Arnold et al., 2012). Applying spark discharge soot particles coated with a defined nanometer layer of n-hexadecane, it could be shown, that it is possible to completely remove such a layer with an evaporation tube (see figure 1). Thereby the counting efficiency of the condensation nucleus counter is used to indicate complete evaporation of the coating. Additional measurements with hydrocarbons and solid particles were conducted to further investigate volatile particle removal efficiency and solid particle penetration.

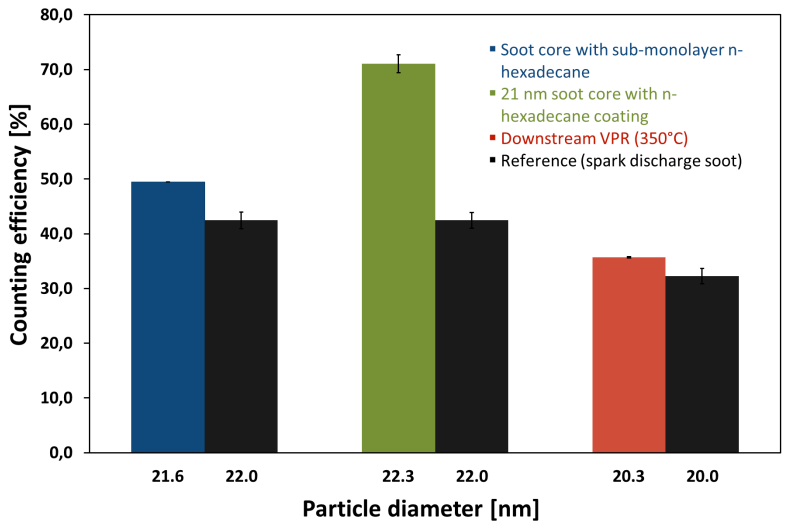


Figure 1: Efficiency of evaporation tube in removing n-hexadecane coating from particles.

**Køcks M. / Danish Technological Institute**

## Real-time Characterization of Particle and Gas Emissions from Construction Equipment during Operation

The hazardous effect of combustion-generated particles is generally recognized and well documented in the scientific literature. They are related to a number of diseases such as reduced lung function, cardiovascular diseases and increased mortality, and in particular, exposure to nanoparticles is suspected to have a significant negative impact, since nanoparticles can penetrate deep into the lungs (alveoli).

For improving the air quality, it is necessary to reduce the number of nanoparticles as well as the $NO_x$ concentrations. For example, the health related EU exposure level for $NO_2$ (40 $\mu g/m^3$) has been exceeded several times within the last 5 years in the vicinity of one of Copenhagen's major boulevards. In this context, construction equipment is responsible for a significant part of the total particle and $NO_x$ pollution in urban areas, partly because non-road machinery is not subject to the same regulatory emission standards (Stage standards) as road traffic (Euro standards). An important issue relating to construction equipment is that the construction site workers are very close to the emission source, and hence significantly exposed.

In this study, real-time emission data from three diesel-driven, medium-sized construction machines during real-life operating and emission conditions is shown. Machinery included in this study are: One asphalt paver (without DPF) and two similar asphalt millers (with and without DPF). Measurements are carried out from a van driving right next to the machines on a test facility, and measurement probes are connected from the construction equipment exhaust to measurement equipment inside of the van. Particle size and number concentration (PNC) are measured in the size interval 10-350 nm using a NanoScan SMPS (TSI) connected after a rotating disc diluter (Matter) and a catalytic stripper (Catalytic Instruments). Gas emissions are measured using traditional laboratory gas measurement equipment.

In conclusion, the measurement approach and setup with a van driving next to the construction equipment was successful and real-time emission data was acquired during real-life operating conditions. The measured nanoparticles are relatively large and very few solid particles are observed near and below the PMP (Particle Measurement Program) cut at 23 nm.

During spring/summer 2015, this preliminary work will be followed by development and implementation of DPF and SCR (Selective Catalytic Reduction) technology for the asphalt paver, and two different SCR technologies (urea vs. solid ammonia dosing) with different catalytic coatings will be compared. The effects of these approaches will be documented by similar on-site and real-time emission measurements.

This study is part of a 2-year Danish project (2014-2016), co-financed by the Danish Environmental Protection Agency, and the consortium is constituted by Danish Technological Institute and the companies NCC Roads, Purefi and LiqTech International.

**Kral K. / AutoVision Germany**

## Evaluation of Aerosol Particle Characteristics with different Conditioning Units

We present the influence of different aerosol conditioning units on synthetic produced model aerosol for the validation of particle number systems. Our work manly focuses on the effect to the dilution factor. The results and conclusions of these experiments will be visualized in the poster. For these determinations we used an experimental setup which is shown in figure 1.

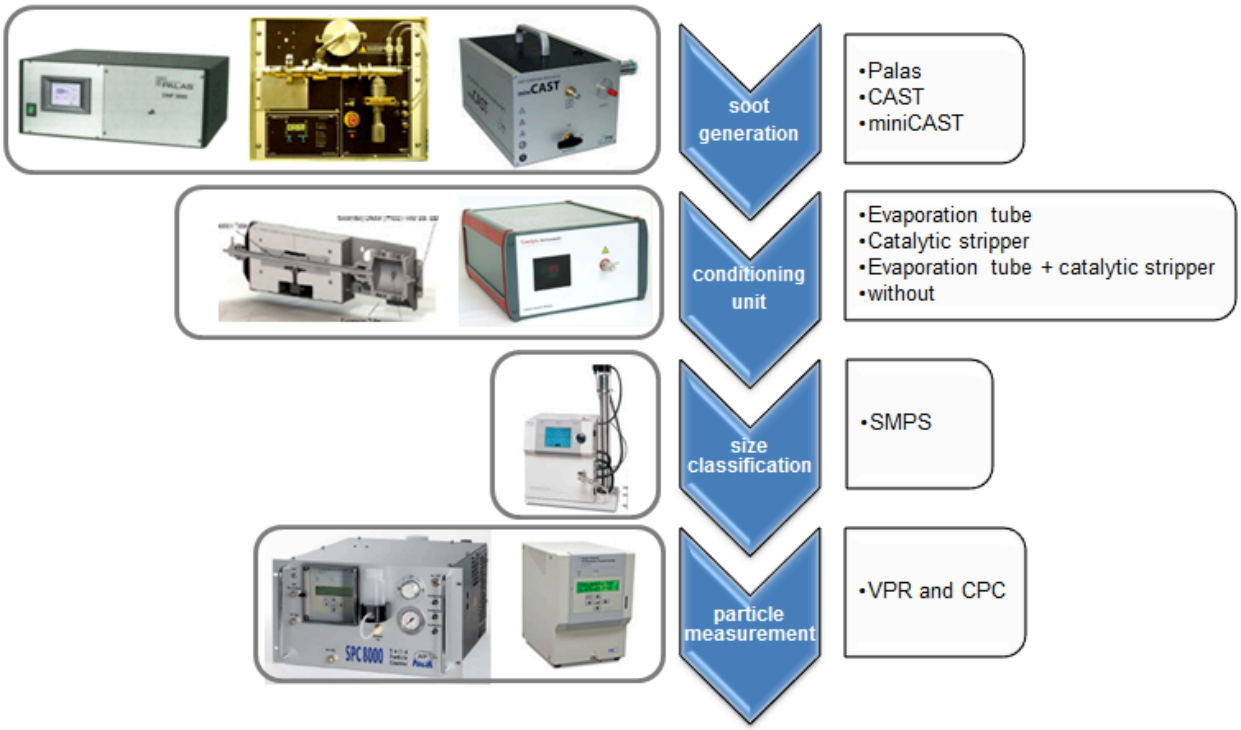


figure 1: experimental setup

**Kutlar Joss M. / Swiss Tropical and Public Health Inst., Switzerland**

## Ultrafine Particles in the Air – what has been Studied Epidemiologically to date?

**Background**
The documentation database of LUDOK (Dokumentationsstelle Luft und Gesundheit) at the Swiss Tropical and Public Health Institute in Basel selects, categorizes and summarizes relevant research papers on the topic of ambient air pollution and health outcomes for the Swiss Federal Office of the Environment since 1985. Population based studies on the health effects of ultrafine particles on human health are more and more published. We aim to give an overview on the current state.

**Methods**
From a monthly systematic search query in PubMed and alerts from important journals the research team selects continuously relevant papers for the LUDOK database. We will give an overview over the published literature on epidemiologic research on the health effects of ultrafine particles, measured as numbers of particles usually of less than 100 nm in diameter.

**Results**
Publications on particles have risen constantly over the years. LUDOK contains to date (10.3.2015) over 3690 articles on particles, of which 395 articles investigated or discussed ultrafine particles and their impact on health. After excluding cell- and animal-studies, sole exposure studies, overviews and discussions and studies that have not investigated ultrafine particles measured as numbers of particles, there remained about 160 studies that have investigated ultrafine particles and health. A closer study of the 126 papers included since 2007, revealed that almost all studies looked at short-term effects (96%). The outcomes in those studies were cardiovascular disease or end-points such as heart-rate variability or blood pressure 34%), changes in markers for inflammation or on cellular level (24%), respiratory health and disease (13%), hospital admissions or emergency department visits (10%), mortality (7%), and other (1%) outcomes in association with UFP levels a few hours or days before measurements of those outcomes. The five long-term studies looked into changes in markers for inflammation or on cellular level (2), on respiratory health and disease (2) and depressive symptoms. Only 8 short-term studies and none of the long-term studies have analyzed associations of health with the number of particles while simultaneously adjusting for other pollutants from similar sources or with similar spatial resolution such as, e.g., NOx, EC, or CO.
Important contributing studies include the KORA cohort (GER), the experimental RAPTES project (NL), the Normative Aging Study (USA), AIRGENE (GER), TRAVEL (NL), ULTRA (FIN) and others.

**Conclusions**
There is a gap in the current research on the effects of ultrafine particles and their long-term effects on human health. Short-term effects have been studied more often. However, the independence of their effects from effects of other air pollutants still has to be evaluated in two- or more pollutant models.
Whether numbers of particles, a nonspecific indicator for ultrafine particles, have independent effects from other air pollution metrics still has to be shown in future research.

LUDOK has been a valuable source of information for researchers, policy makers and local authorities in Switzerland.

**La Rocca Antonino / University of Nottingham**

## Electron Tomography of Combustion Generated Nanoparticles

Transmission Electron Microscopy (TEM) is amongst the most widely used techniques available to characterize combustion generated nanoparticles such as soot; despite being an established analysis technique, TEM allows measuring the particle shape and size of projected two-dimensional images of agglomerates. It does not allowfor the three-dimensional nature of agglomerates, and will generally underestimate their true maximum length; 10-20% smaller as suggested by Rogak [1]. This work explores a novel method to assess surface area of soot nanoparticles and their actual volume using three dimensional models built via tomography reconstruction. The development and application of 3D-TEM for characterisation of soot agglomerates will pavethewayfor exciting new characterization capabilities to yield information of volumetric character of fractal nanoparticles. The recent developments achieved in electron microscopy and tomographic techniques have shown the potential for volume reconstruction of nanometric objects frommultiple imaging at different tilt angles. Electron tomography (ET) is a technique where a 3D tomogram can be formed from a set of 2D images taken from an electron microscope, normally a transmission electron microscope. In the bright field (*BF*) mode of the *TEM* mass thickness contrast is dominant and 3D reconstruction have been successfully demonstrated to study location and distribution of metal (oxide) particles in zeolites and catalyst materials. The novelty of this work is to extend the well-developed practices and capabilities to light element, light structures such as soot nanoparticles. This investigation looks at the feasibility for volume reconstruction of nanometric soot particles from multiple imaging at different tilt angles. Soot in a heptane solution allows deposition onto TEM grids. Following deposition, the solvent evaporates rapidly to leave soot particles of varying sizes, without aggregation during drying on the grid. This technique allowed for images from -60 to +60 degree tilt with no sign of carbon build up to be acquired. Gold particles, as fiducial markers, were added to help with tilt series alignment.
A key challenge with BF TEM images is to obtain a clear contrast through the entire tilt range. Particular attention has to be placed in acquiring the 2D projections minimising missing information which results in reconstruction artefacts such as elongation effects. The IMOD reconstruction software was used in this investigation. Two most common reconstruction techniques, based on back-projection algorithms (WBP) and iterative approaches (SIRT) were tested. When comparing the tomograms, the WBP method produced a clearer tomogram than the SIRT method. To further improve the quality of the tomogram the AND filter was used, which helped improve the signal to noise ratio (SNR). The 3D models were also produced within IMOD, by outlining the soot particle layer by layer, with a completed model shown in Figure 1. A Matlab script was exercised to predict surface area and volume of the agglomerates.

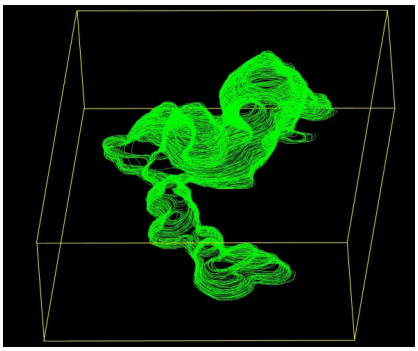

Figure 1. Volume renders of 3D visualizations of soot nanoparticles

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**Lee Chun Beom / KATECH, Korea**

## Multi-purpose High Temperature Exhaust Gas Simulator

To satisfy the enforced exhaust gas regulation nowadays, various exhaust gas treatment systems such as Cooled EGR, DPF, SCR, LNT, DOC, TWC and high temperature sensors to meet the OBD criterion such as $O_2$, $NO_x$, T, $\triangle P$ are necessary, due to this situation, cost increase and reliability/durability problem is the hot issue of after-treatment technologies.
To develop these after-treatments systems and to verify the performance of parts, we are using basically real engine and engine dynamometer to test and evaluate the components. But this method requires a lot of time and cost, in addition this engine test method is a difficult method to test and evaluate the characteristics of parts such as the parametric test according to the associated parameters such as temperature, mass flow rate, oxygen contents, toxic gas concentration, soot and SOF
This high temperature exhaust gas simulator can make up for the shortcoming of the engine dynamometer test and this simulator has a capability of characteristic test according to the variables such as precisely and independently controlled temperature and mass flow rate and oxygen concentration and soot/SOF deposition.
Especially this simulator has a capability of fast aging test and reliability test and the simulating test of steady state D-13 mode engine test to verify the required performance of OEM.
This simulator was appraised as an instrument reducing the R&D duration and cost from many Korean parts company and OEM and also proved having a Long life cycle and High speed response, Precise control of Temperature and Mass flow rate and also gives a capability of GUI base Computer controlled test simulating the Engine dynamometer.
For the last 10 years, by using this simulator we developed the EURO-4, EURO-5 and EURO-6 technologies like as ;

- EGR Cooler and EGR Valve: Pressure drop, effectiveness, thermal shock, reliability, fouling test of soot/SOF
- Catalyst(TWC, DOC, SCR, LNT): Conversion efficiency, thermal shock, durability, aging effects
- Particulate filter(DPF, GPF, pDPF): Pressure drop, oxidation rate of PM, regeneration, thermal shock, durability
- High Temperature sensor($O_2$, NOx, T, delP): Response time, interference, stability, thermal shock, durability, weak point detection and failure scenario check

**Lee Jeonghoon / Korea University of Technology and Education**

## Black Carbon Concentration at an Inland Area in Korea

Black carbon (BC) concentration at an inland rural area was monitored and the pattern of diurnal variation was found to be similar to those measured in urban areas. Our monitoring site is not rural exactly nor urban because it is surrounded by farming fields, mountains and a stream but there is a factory in the vicinity of the campus. Thus, our monitoring site can be redefined as a rural area with an urban-type fixed source. The BC concentrations show similar patterns between weekdays and weekends. On weekdays, BC concentrations were definitely influenced by traffic density since the daily pattern of traffic density during the morning and evening rush hours was similar to that of BC concentration. On weekends, however, the diurnal patterns of BC concentration were presumably influenced by several causes including pollutants from the adjacent factory, biomass burning, burning of straw pile at farming fields, and so on. In the spring season, the BC concentration was relatively high because of various factors. First, the wind is blown from the west where a factory is located. Second, the burning of haystacks is frequent in the spring season, increasing the BC concentration in April. Third, traffic density increased because of the start of a new school semester. But the BC concentration was reduced in the summer season because of the precipitation of rainfall and turbulent mixing by the wind. In September, however, the BC concentration increased again because of the wind from the west. Traffic density was monitored and it partly affected the increase in BC concentration in the morning and evening. Interestingly, the BC concentration measured at night was higher than that measured during the day. The factory is believed to be a second contributor during weekdays but becomes a main contributor on weekends. It is believed that the local influence from neighbor contributed to the increase in the BC concentration at night. The burning of haystack and biomass burning of excreta from cows, ducks and poultry seem to be minor contributors. The BC/EC ratios obtained in the present study lay in between the value measured at an urban site and the value measured at a rural site. They also showed similar trends to those measured elsewhere in Europe.

**Lehtoranta K. / VTT Finland**

## Impact of SCR on particle emissions in HFO application

### Introduction

NOx and SOx emissions from ship exhausts are limited by IMO (International Maritime Organization) ship pollution rules. NOx emission limits are set for diesel engines depending on the engine maximum operating speed. Limits are set globally (Tier I and Tier II) and in addition for emission control areas (Tier III). Tier III standard is dated to 2016 and is expected to require the use of emission control technologies. SCR (selective catalytic reduction) is an available technology capable of meeting this requirement. This technology uses a catalyst and ammonia for the reduction of NOx to elemental nitrogen. On the other hand SOx limits are requiring the use of lower sulphur level fuels or after-treatment systems, like scrubbers, to decrease SOx emissions while allowing the use of inexpensive heavy fuel oil (HFO). The PM is expected to decrease indirectly through the SOx limitations (by reduction of sulphate particle emissions), but at the moment, no direct PM limitations exist.

### Experimental

In this study, a partial flow test bench was used to study (smaller) SCR units with a proper exhaust gas from a medium speed diesel engine. A heavy fuel oil with a sulphur content of 2.5% was utilized as test fuel. Two different SCRs, having differences in structure ("SCR A "- an extruded honeycomb type and "SCR B" - a packed bed reactor), were tested similarly using engine load of 75%. In addition, different exhaust temperatures were utilized in testing. The effect of SCR on particle emissions was studied by collecting particles on filters both before and after the catalyst according to the ISO 8178 method. The particle filters were further analysed for sulphates and organic and elemental carbon. In addition ELPI was employed to study the particle number size distribution. For NOx a chemiluminescence analyser was in use and FTIR was used to measure the NH3 and SO2.

### Results and discussion

The results show that similar NOx reduction efficiencies can be achieved with both SCR units at exhaust temperature of 340-450°C. However, at the same time, the PM results were found to vary significantly. Higher PM levels were measured downstream of SCR B. Also, a clearly higher nanoparticle mode was found downstream of the SCR B than what was measured without any catalyst. Recently, the size distribution result downstream of the SCR A showed a decrease in nanoparticle concentration compared to the one measured without any SCR (Lehtoranta et al. 2015). Both size distributions are presented in Figure 1. The sulphate formation was also found to enhance with the SCR B indicating sulphur has a significant role in nanoparticle formation. For the SCR operation the exhaust temperature was found to be important as well as the soot accumulation in SCR.

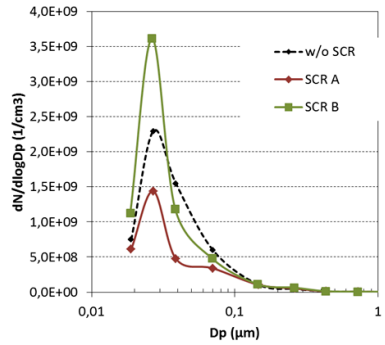



Figure 1 Particle number size distributions measured without any SCR and downstream of "SCR A" (honeycomb styled) and "SCR B" (packed bed reactor).

**Leskinen A. / Finnish Meteorological Institute & University**

## Aerosol Measurements in Nanjing, China

Air pollutant levels in China have increased during recent years due to rapid industrialization. Measurements of particle mass and gas species are already conducted in many Chinese cities but climatically more relevant particle size distribution and black carbon measurements are still quite rare.

We have started such measurements in the megacity of Nanjing in November 2014. Nanjing is located in Eastern China in Yangtze River Delta region, where exist many regional air pollution sources, such as industry (electronics, automotive, smelters, petrochemistry), traffic, energy production with coal, and burning of agricultural waste.

Our measurements comprise aerosol size distribution in the size range of 10 nm – 10 µm with a TSI 3910 Nanoparticle Sizer and a TSI 3330 Optical Particle Sizer, black & brown carbon concentration with a Magee Scientific AE-42 7-wavelength (370 nm to 950 nm) aethalometer, and weather parameters with a Vaisala WXT520 weather station. The measurement site is located at the Nanjing University (NJU) Xianlin campus, on the rooftop of a five-floor building. We have analysed the data according to wind direction and time of day.in order to provide more knowledge about the emissions from the regional sources.

Between November 2014 and March 2015, the average and peak total particle number concentrations have been 16000 and 128600 $cm^{-3}$, respectively. The peaks occur usually at around 6 am and 6 pm, the times when commuting traffic is at its highest. The fraction of submicron particle is higher when the wind blows from the direction of nearby highways. The fraction of coarse particles is, in turn, higher, when the wind blows from the construction sites nearby.

The average black carbon concentration (at 880 nm) during the same time period was 2.95 $\mu g/m^3$. The fraction of black carbon to total particle mass concentration (calculated from the number size distribution by assuming spherical particles with a density of 1.0 $g/cm^3$) varied between 0.03 and 0.23. Accordingly, the absorption Ångström exponent ,calculated from the 370 and 880 nm wavelength pair, varied between 0.6 and 1.6, indicating existence of some non-absorbing material, and/or brown carbon, in particles at times.

**Luttinger A. / PEMRED Switzerland**

## Particle Agglomeration Inducer application in EURO-II Heavy Duty truck retrofitting

China is confronted with millions of legacy EURO-II trucks, which due to economic constraints cannot be scrapped before several additional years of operation. Such “Yellow Label” trucks have circulation restrictions, which can be removed by retrofitting an after-treatment solution. One of the first cities to experiment with such solutions is Ningbo, the second largest portal city in China.

The Ningbo Port Authority is conducting a Yellow Label retrofitting project in order to reduce the emissions pollution of these trucks, starting with the Huizhong Container Truck.

A popular initial choice for retrofitting is the Diesel Particulate Filter (DPF), known for its efficiency in modern diesel vehicles. However cost and complexity consideration nurture a continuing interest in alternative solutions.

The present poster highlights the results and conclusions of a retrofit road trial in Ningbo, using the Particle Agglomeration Inducer to improve the performance of a DOC-POC after-treatment in EURO-II trucks using high-sulphur fuel (PAI-DOC-POC). That solution is entirely passive without any fuel additives.

An initial validation of the PAI-DOC-POC configuration was conducted at Dinex labs, showing the increase in ultrafine particles emissions due to the installation of a DOC-POC device and subsequent reduction when the PAI is added.

A preliminary test of the operating conditions of the Huizhong truck concluded that it was incompatible with a passive DPF retrofit because the exhaust gas temperature is well below the DPF passive regeneration requirements, even with a fuel borne catalyst.

An alternative choice for this truck is Particle Oxidation Catalyst (POC). It requires a regeneration temperature of 300°c, which is compatible with the Huizhong truck. But the POC trapping efficiency is lower than that of a DPF - and that is where the Particle Agglomeration Inducer improves the standard POC efficiency. It enabled more efficient particle filtering while also reducing the ultrafine particle emissions.

Clearly, the POC remains a second choice compared to a DPF due to its lower PM trapping and risk of spontaneous soot release in case of incomplete oxidation. Yet it should be evaluated in light of the pragmatic alternatives.

*Main conclusions.*

The installation of exhaust after-treatment devices increases the exhaust back pressure, resulting in higher ultrafine particles emissions. The addition of the Particle Agglomeration Inducer upstream of a standard DOC-POC device increases its trapping efficiency while also reducing the ultrafine particle emissions. A Huizhong container tractor was retrofitted with a PAI-DOC-POC solution and drove more than 19,000km with an average of 400km per day at speeds up to 60kmh, without any operating incidents or noticeable increase in fuel consumption. A PM2.5 test was conducted upon the installation (clean unloaded devices) and the reduction rate exceed 70%. A PN test was conducted after 19,000km and the reduction rate exceeded 99%. A visual examination of the POC outlet revealed an almost clean substrate, attesting to a high soot oxidation efficiency.

Additional tests and trials are to be conducted to validate the consistency of the solution, which could significantly improve the air quality of transport intensive industrial, mining and portal regions in China.

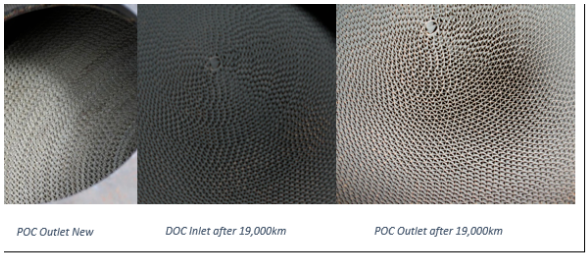



Figure 1 - DOC-POC state new and 19,000km

**Mamakos A. / AVL Austria**

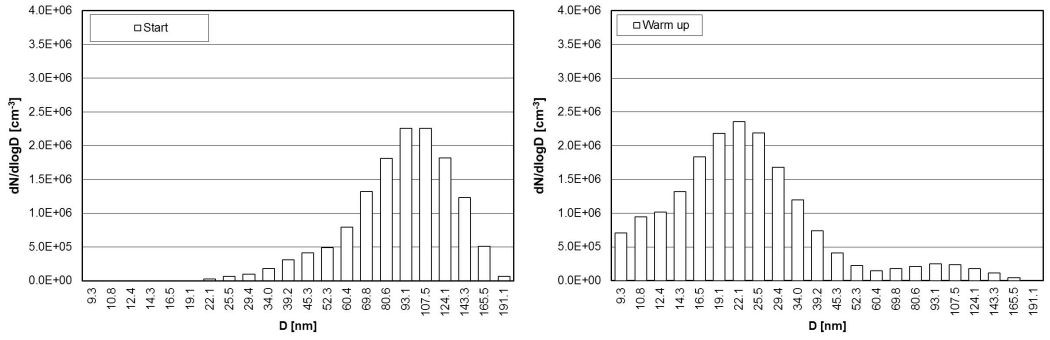
## Bringing the PMP Methodology on-Board

The upcoming Euro 6 legislation introduces the requirement for real world emissions assessment for the type approval of vehicles entering the European market in 2017. In the case of gaseous pollutants, on-board measurement with Portable Emission Measurement Systems (PEMS) was already decided. The suitability of PEMS instrumentation for Particle Number (PN) emissions is currently under evaluation by the European Commission.
The regulated PN measurement procedure only addresses the solid fraction of the exhaust aerosol. Volatile particles are removed by means of thermodilution (UNECE regulation 83): a) the aerosol is heated at 300 to 400ºC to bring volatile compounds in gas phase, and b) diluted to reduce their vapour pressure to level that would hinder their renucleation or at least growth to a size that could be detected by a Condensation Particle Counter (CPC) having a 50% detection efficiency at 23 nm.
Implementation of the regulated PN procedure in a PEMS device poses a number of challenges, especially for light duty applications, where weight and power constraints are more crucial compared to heavy duty installations. Perhaps the most challenging element however remains the on-board use of CPCs. While handheld devices are already commercially available, they are not robust enough to withstand the harsh environmental conditions under real-world driving, while the use of alcohol as working fluid also poses safety hazards.
Here we present the development of a PN-PEMS device utilizing a diffusion-charger. The operating principle of the sensor is based on the measurement of induced currents produced by modulating the charge state of the particles. This allows for a real-time determination of electrometer zero levels, thus allowing for reliable measurements even at levels close to the instrument noise. Different approaches can be employed for the production of the space-charge pulses, allowing for an unparalleled control of the raw signal dependence on particle size. A good correlation with CPCs can thus be established over a wide size range, without the need for inversion algorithms and assumptions on the form of the underlying size distribution.
The wide operating range of the sensor, also allows for the use of a simple and robust dilution scheme using critical orifices for sampling, and a single mass flow controller for the supply of conditioned dilution air maintaining a fixed dilution at 10:1, irrespective of the ambient pressure. The use of a temperature-controlled critical orifice also implies a fixed volumetric flow through the sensor irrespective of the altitude, which is crucial for the optimal modulation of space-charge pulses.
To compensate for the rather low dilution compared to that typically employed in the regulated methodology (>1000:1 including the Constant Volume Sampler) a three-stage thermal treatment is employed, using an evaporating tube, an oxidation catalyst and a sulfur trap in series. The two catalysts effectively reduce the concentration of organic compounds and sulfates without dilution, while the evaporating tube allows for an efficient diffusion of the species on the catalyst sites.

**Markowski J. / Poznan University Poland**

## Particulate Emissions from Jet Engine

Parameterization of the emission limits from aviation engines shown in Annex 16 of the ICAO Convention provides information on the exhaust smoke. In order to expand the information about the quality of exhaust gases from jet engines the studies of size distribution of particulate matters have been carried out. The jet engine used in the studies was equipped with annular combustion chamber, into which fuel is supplied using a fuel vaporizer. The engine is characterized by generated thrust of 10.8 kN, and therefore it is not the subject of emission standards described in Annex 16 of the ICAO Convention. Measurements of the size distribution of particulate matter were carried out on the engine operation resulting from the implementation of the pre-flight test of the aircraft. Measurements were made for chosen settings of engine power control levers during the warm-up and the relative values of thrust force set at 40%, 70% and 95%. The engine was powered by standard fuel designed for turbine engines. The results of measurements show that for all engine operating conditions particles' dimensions were in range of 9.31 to 191.1 nm. Distribution of relevant particle diameters indicates that about 95% of the particulate present in the exhaust gas were in size range of 16.5–45.3 nm. The population of particulate matters present in this size range is highly dependent on engine load. During the engine warm-up when the engine load is relatively small, the concentration of emitted particles is small. With the increase of the engine load up to 40% of the maximum value the increase of particle number concentration in the exhaust was observed. Assuming the concentration of particles at mentioned value of engine load as a benchmark for other values can be concluded that the growth of engine load to 70% results in approximately two times increase of particles number. The growth of engine load to 95% of the maximum effects in there times increase of number of particles. In addition, it was found that an increase in thrust reduces value of characteristic diameters of the dimensional distributions of particulate matters.




In the case of the operation of airplanes maximum engine load value occurs during start-up, so rightly special attention was paid to the issue of the location of new airports by locating them away from the urban area, and leads the development of low-emission combustion chambers and the growing use of engines with high grade of bypass.

**Mazaheri Mandana / Queensland University of Technology (QUT), Australia**

## Environmental Factors Affecting Exposure to Ambient Ultrafine Particles at Urban Schools

The adverse health risks of ambient particulate matter exposure on respiratory and cardiovascular systems have been well recognized, contributing to higher emergency department visits, hospitalization and mortality (Brunekreef et al. 2009; Hoek et al. 2013; Kheirbek et al. 2013; Krewski et al. 2009; Pope et al. 2009). Children's exposure to air pollution and characterizing their exposure-response relationship has been of a great interest recently. Until 2011, most of the efforts in school-based air quality studies were focused on particulate matter in terms of particle mass and in the PM2.5 and PM10 size ranges (Mejía et al. 2011). Some comprehensive studies on the ultrafine particles (UFP) characteristics at schools have been conducted in the past few years, including in Australia (Ultrafine Particles and Children's Health (UPTECH) epidemiological study) (Crilley et al. 2013; Crilley et al. 2014a; Crilley et al. 2014b; Laiman et al. 2014; Mazaheri et al. 2013; Salimi et al. 2013; Salimi et al. 2014), Spain (BRain dEvelopment and Air polluTion ultrafine particles in scHool children (BREATHE) study) (Reche et al. 2014; Viana et al. 2015), Italy (a smaller scale of the UPTECH) (Buonanno et al. 2013; Buonanno et al. 2011; Buonanno et al. 2012a; Buonanno et al. 2012b), and the US (Zhang and Zhu 2012). The importance of site specific environmental factors affecting UFP exposures in school microenvironments has been highlighted in all these studies.

This work uses the already available comparative sets of data that were collected in urban schools within the frameworks of the UPTECH project in Brisbane (Australia) and project in Barcelona (Spain). UPTECH data collection comprised of continuous air quality measurements for 2 weeks at 25 schools and at one school at a time, within the Brisbane Metropolitan Area from October 2010 to August 2012. BREATHE air quality data were collected for one-week in 36 schools in Barcelona and 3 schools in a lower trafficked area in comparison to Barcelona (Sant Cugat del Vallès - 7km away from Barcelona city) in two sampling campaigns: first campaign from 27 January until 22 of June 2012; and second campaign from 14 September 2012 until 22 February 2013.

The employed data in this work consist of time-series of UFP concentrations in the size range of 10 – 300nm that were measured indoors (teaching classrooms) and outdoors (within the school grounds) as well as the elemental and organic carbon concentrations in the PM2.5 samples, traffic and meteorological conditions at each school. The recorded metadata on each school's characteristics and potential parameters affecting indoor and outdoor schools air quality are also available.

The exposures, defined as the total UFP concentrations, are quantified for school-based and area-based scenarios for each study area. The exposure trends and magnitudes are analysed in order to determine and compare the influencing parameters driving children's UFP exposure in Brisbane and Barcelona.

**Melas A., Aristotle University of Thessaloniki Greece**

## Oxidative Fragmentation of Soot Aggregates

Over the last years, legislation on particulate matter emissions of diesel cars focuses on ultrafine particles (smaller than 100nm) which are claimed to be responsible for climate change and irreversible health effects. It is characteristic that in Euro 5b, a particle number limit was introduced in addition to the already existing particulate mass limit. Particle number and size distribution are unstable and depend on internal processes like coagulation and fragmentation (Friedlander, 2000). While the coagulation kernel has been extensively studied in the literature (e.g. Kostoglou and Konstandopoulos, 2001), there is still lack of understanding about the fragmentation mechanism.

Harris and Maricq (2002) found that soot particle size distributions from various types of diesel engines have a lognormal shape which may be predicted from the solution of the fragmentation-aggregation equation with Brownian coagulation in the continuum regime. Kostoglou and Konstandopoulos (2003) introduced a more-physically based fragmentation mechanism. Accordingly, fragmentation of the soot aggregates is assumed to occur due to surface oxidation of the solid contacts between the primary particles, the so-called “necks”. Necks are smaller than the primary particle size and fragmentation may occur before a significant reduction of the primary particle size.

Herein, we study the behavior of well-characterized soot aggregates generated by CAST in a heated reactor at temperatures up to 850$^{o}$C. Two different oxidants are used ($O_2$, mixture of $O_2$ & $NO_2$) and different measurement techniques are applied in parallel. For both oxidants, after the burnout of 50 to 70% of soot, a particle number increase and a new particle size distribution are observed. Particles with diameters similar to primary particle diameters appear initially in small concentration, which increases as the temperature increases. A preliminary attempt to understand the fragmentation process impact on the aggregate population dynamics is done by formulating a Monte-Carlo simulation of aggregate fragmentation. The results of the simulation substantiate some of the experimental observations.

**Mendoza-Villafuerte P. / European Commission**

## Results of the PM Pre-Pilot Program.

The EU PEMS PM Evaluation program was launched in 2008 by the European Commission to assess the potential of portable instruments to measure particulate emissions on-board of vehicles; this is a voluntary program, receiving contributions from the European Joint Research Centre (JRC), some portable emissions instrument manufacturers (AVL, Control Sistem, Sensors Inc, Horiba) and the European association of heavy-duty engines manufacturers (ACEA) in collaboration with the member states. The PM Pre-pilot program was run as a preamble to the PM Pilot Program.

The objectives of the Pre-pilot program were to: (i) Perform a baseline test in order to analyse the comparability of the results and installation issues between the participating instruments, (ii) Perform a correlation study on the results of the PEMS PM instrument with the testing cell reference measuring device, (iii) Perform a correlation between the results of the participating instruments based on on-road test data and (iv) look into the logistics necessary to mount both the PEMS PM and PEMS gaseous instrumentation in a HDV. The tests were run on a Euro IV N3 vehicle.

Both dyno and on-road experiments were performed, on the dynamometer-based tests the WHVC was used as the standard cycle and was run both in cold and warm conditions. Steady vehicle speed cycles were also performed on the dynamometer. On-road measurements were performed using a unique trip containing shares of operation of urban, rural and motorway.

Results show a good correlation between the PEMS PM instrumentation and the chassis dyno emissions system; this is also the case for the correlation between PEMS PM instruments during the laboratory and on-road measurements. The on-road measurements show good agreement between calculated grams per test using integrated PM over the total work performed in the trip. Although there is good agreement when comparing integrated PM mass emissions, a significant spread was found while comparing the CF resulting after analyzing the PM real-time signal with the MAW method.

**Minagawa Tomohiro / Tsukasa Sokken Japan**

## Development of a Next Generation Opacimeter by using the Light Scattering and the Light Absorption Method for Periodic Technical Inspection Use

Diesel particulate filters (DPFs) have usually ability to remove near 100 % of particulate matter (PM) in engine exhaust. DPF is indispensable to emission control for diesel engines. The filtration efficiency of DPF is detected by on-board diagnostics (OBD) device or the periodic technical inspection (PTI) emission test. However the opacimeters in current use cannot detect the latest regulation PM level that is around 5mg/km.
Recently, in order to detect such low level PM, the laser light scattering photometry (LLSP) was developed. LLPS is high sensitivity and high resolution compared to the opacimeters in current use.

In this study, sampling type (partial flow) PM instrument using LLSP was developed for PTI PM emission test. The correlation of light absorption coefficient (k value) measured by light extinction and light scattered intensity was calibrated using soot particles generated by combustion aerosol standard (CAST). The developed instrument can measure the PM by LLSP method and traditional light extinction method. Consequently, it can measure by both methods simultaneously with single measurement cell using single light source (Laser 650nm). Therefore, by using this calibration method, it does not need reference opacimeter. It is well known that the scattered light intensity is affected largely by particle diameter. In this study, at 135°scattered angle, scattered light intensity from the particle distribution of 156nm was approximately 2 times higher than that from the particle distribution of 88nm at fixed k value. The effect of particle diameter on scattered light intensity was found to be compensated by light intensity ratio of two scattered angles (45° and 135°).

To investigate the applicability and practicability for PTI emission test, PM measurements of the free acceleration are conducted for in-use vehicles. At the vehicle with a DPF, the scattered light sensor on the developed instrument could detect PM emission synchronized to free acceleration operation. On the other hand, a traditional light extinction opacimeter could not detect PM emission. At the vehicle without a DPF, the measured k value using light extinction sensor on the developed instrument was confirmed to have a good correlation with the measured k value using a traditional opacimeter. Then, it was found that the developed instrument can apply to not only modern diesel vehicle but also high emitting diesel vehicle for PTI test.

**Monjezi Mojdeh / Sharif University of Technology Tehran, Iran**

## Modelling the Transport of Inhaled Nano-Particles from Human Lung to Whole Body using Compartment Method

Inhaled nano-particles can have both toxic and therapeutic effects on human. Carbon nano-tubes, asbestos fibers and other industrial nano-materials could cause pulmonary diseases. On the other hand inhaled nano-particle drugs have been developed for treating pulmonary or systemic diseases. Thus, many researches in the area of inhaled nano-particle retention and clearance have been developed. In this research a multi compartmental model has been developed that can predict the bio-kinetics of insoluble nano-particles translocation from lungs to systematic circulation, lymphatic systems, gastrointestinal tract and organs. In order to calculate the amount of nano-particles in each compartment, a system of differential equations quantifying the transport of particles from one compartment to another were solved. Experimental retention of nano-particles in the rat lung was used to find transport rates in the model equations. The model transport rates were found by minimizing the mean square error existed between the model and experimental retention data. The calculated transport rates for the rat were converted to the human ones using a valid alometric scaling method. This model provides a complete specification of the residence time of nano-particles in the lungs, blood circulation and other key organs of the body and can be used in diverse fields such as toxicology for exposure-risk analysis and respiratory nano-drug development and targeting.

Nanoparticle deposition in the mouth, trachea, bronchia and alveoli during inhalation was obtained by the program multiple-path particle dosimetry and was used as an initial condition of the corresponding equation. Kolanjiyil and Kliensteruer (2013) showed that only 0.2% of the nano-particles were translocated to the olfactory region within 800 days. So, we have not considered the olfactory compartment in the model. One of the modifications in our model is that the mouth is added as a separate compartment in which nano-particles could transfer to the gastrointestinal track or blood. Another modification is related to presence of nanoparticles in mouth or other compartment after inhalation instead of considering that nanoparticles are deposited only in the lung. Our results showed that the amount of 4.2% of the initial nano-particle deposition will translocate from the lung to the lymphatic system. The human lung alveolar retention after one day is 95% which is in accordance with the experimental results of Moller et al and verifies our modelling. This indicates that clearance mechanism in the lung is very slow and repeated inhalation of nano-particles from combustion process or environmental atmosphere will cause pulmonary diseases.

The nano-particle translocation to systemic circulation is about 0.1% of the initial deposition after one day. The amount of nano-particles which could reach the other organs including heart, kidney and liver from blood circulation is about 4.2% of the initial deposition. Although a small amount of deposited nano-particles could transfer to these organs, the accumulation of the nano-particles could cause nonreversible side effects.

**Mønster J. / FORCE, Denmark**

## Validation and Application of a novel Optical Particle Counter

Several studies the last few decades have confirmed that elevated concentrations of particulate matter causes an increase in health related issues. Combustion generated particles are generally relatively small and recent studies have focused on the effect of smaller size fractions of the particles pollution, such as $PM_{2.5}$ and $PM_1$, as these have the ability to penetrate deeper into the human respiratory system and cause damage. Various measurement systems have been developed based on different detection principles in order to measure the number concentrations and mass of the smaller particles in the air. Many of the developed systems are large, heavy and power consuming, limiting the applications to mainly stationary measurements. Recent development within optical measurement methods has made it possible to measure the masses $PM_{10}$, $PM_{2.5}$ and $PM_1$ using small, portable and low power consuming instrumentation. However, the optical method has some limitations with respect to the smallest size of particles that can be detected.
We have tested a small, novel optical particle counter (OPC-N1 from Alphasense, UK). The specifications of the particle counter allows counting the number of particles in 16 size bins between 0.38 and 17.23 µm in diameter. The test was performed in the laboratory, using standard size particles and diesel combustion particles and the performance of the optical particle counter was compared with an Electrostatic Low Pressure Impactor (Dakota, Finland) and a Scanning Mobility Particle Sizer (TSI, USA). Additionally, we used the optical particle counter for two applications: 1) a quantification of particle exposure inside a helicopter cockpit during airborne measurement of pollutants in ship plumes and 2) comparison of personal particle exposure between biking along roads with different amount of traffic and when using public transportation.
The laboratory instrument comparison showed that the optical particle counter were able to detect particles down to 300 nm, although the counting efficiency was significantly reduced for particles sizes below 400-600 nm (Figure 1). Particles larger than 600 nm were all counted by the OPC-N1.

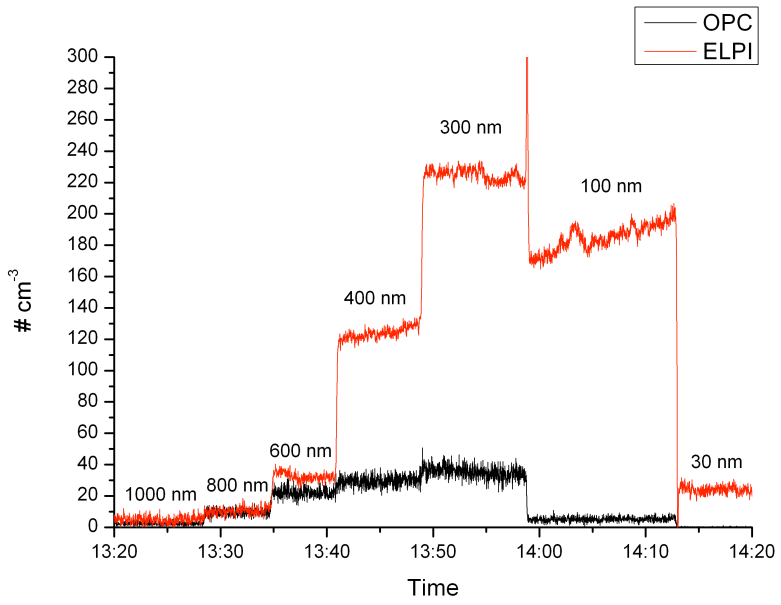



Figure 1. Particle counting at different particle sizes using the optical particle counter OPC-N1 and the Electrostatic Low Pressure Impactor.

As shown in Figure 2, measurements inside a helicopter cockpit during ship plume measurements showed significant increase of particle mass, both for $PM_1$, $PM_{2.5}$ and $PM_{10}$. The concentrations increase significantly, but are well below the National Danish limit values for particle mass in occupational areas.

**Moon G. / Korean register of shipping**

## An Experimental Study on Effect of Sulfur Contents in Fuel Oil on Particulate Emission Emitted from Marine Diesel Engine

The main emissions from ships are nitrogen oxides (NOx), sulfur oxides (SOx) and particulate emission, which are restricted by international maritime organization (IMO) regulations. Among these emissions, particulate emission emitted from ships was indirectly regulated by limit for sulfur contents of fuel oil. Recently, IMO is considering to adapt regulation to reduce particulate emission. This seems to be related to ice melting in arctic region with establishment of northern sea route and more stringent emission regulations. In this respect, it is important role in investigation of emission characteristics with sulfur contents of fuel oil. This study was conducted on 14.6 L 8 cylinders turbocharged marine diesel engine which produces maximum power of 403 kW at the engine speed of 1,800 rpm. The engine fuelled with ultra low sulfur diesel (ULSD, <10 ppm S) and high sulfur diesel fuel (HSD, 3,400 ppm S) to investigate the engine-out particulate emission characteristics under various steady-state engine operating conditions. The mass concentration of particulate emission measured with micro dilution tunnel and micro balance. The number concentration of particulate emission measured by means of the engine exhaust particle sizer with dilutor. The magnitude of blackening of filter paper was measured by smoke meter. The results revealed that noticeable increased in mass concentration of particulate emission for HSD under all operating conditions. With regard to particle size distributions for HSD, the particle number concentration sharply increased in nucleation mode under all operating conditions. Also, total particle number concentration for HSD increased compared to ULSD. Contrary to this tendency, filter smoke number (FSN) for HSD lowered than that for ULSD. From these results, the particulate emission for various fuels need to comprehensive analysis through several measurement methods for better characterization. Conclusively, this study can give an information for developing after-treatment system and establishing of combustion strategy for emission abatement.

**Mühlbauer W. / LTTT Bayreuth Germany**

## Influence of in-Cylinder Soot Formation and Oxidation on Engine-out Soot Emissions in Operation with 1st and 2nd Generation Biofuels

The main challenges for developers of future diesel engines lies in the reduction of the particulate matter (PM)–nitrogen oxide ($NO_x$) trade-off and in the replacement of fossil diesel by alternative / biogenic fuels. In the last years research activities have concentrated on the development of biogenic fuels of the first and second generation, which can substitute fossil fuels [1,2]. Modern diesel engines reach the strong emission limit values, especially for PM and $NO_x$, by exhaust aftertreatment systems (diesel particulate filter (DPF), selective catalytic reduction (SCR)), which are complex, expensive and reduce the total engine efficiency (higher backpressure, additional fuel injection for DPF regeneration) [3,4]. Hence, a solution for this demand is to reduce PM and $NO_x$ emissions during in-cylinder combustion. A promising method to counteract the PM-$NO_x$ trade-off are alternative combustion concepts like homogeneous charge compression ignition (HCCI). Current scientific approaches reach HCCI operation mostly with different injection strategies [5]. The development of new fuels gives a further degree of freedom to achieve the HCCI operation mode. Therefore, in our study the in-cylinder soot formation and oxidation process and their influence on engine-out soot emissions in operation with a first and a second generation biofuel were analyzed by optical measurement techniques.

Rapeseed oil methyl ester (RME) as a representative of the first generation and di-n-butyl ether (DNBE) as a representative of the second generation of biofuels [6,7] as well as reference diesel fuel (CEC RF-06-03, B0) for comparison were used for the tests. The experiments were carried out at different injection pressures on an optically accessible single-cylinder diesel engine. The combustion process was visualized by simultaneous imaging of the hydroxyl radical (OH*) and a spectral range of soot luminescence. This allows the analysis of the in-cylinder soot formation and oxidation process. Changes in physical properties of the emitted particles were measured by a Scanning Mobility Particle Sizer (SMPS) with preconditioning of the exhaust gas according to the PMP (particle measurement program) regulations [8]. Furthermore, important properties of the selected fuels (e.g. density, viscosity, surface tension, distillation curve) were determined by standard fuel analysis methods.

Our measurements show a much more homogeneous combustion for DNBE compared to RME and B0 (Figure 1). The reason for that is the low boiling point of DNBE (wide distillation curve of B0 and RME) and its low viscosity and surface tension in comparison to B0. As a consequence of the nearly homogeneous combustion of DNBE, particle number emissions are obviously lower and the size of the emitted particles is smaller than for RME and B0 (Figure 2). Hence, DNBE enables the possibility to reach HCCI operation of the engine.

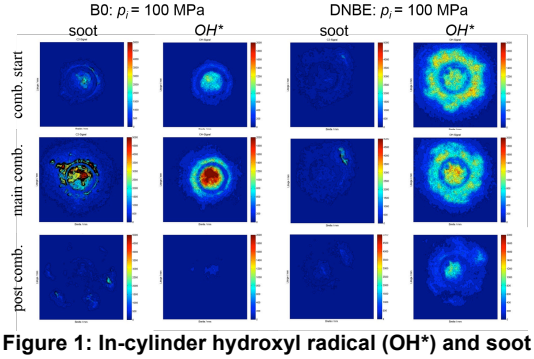



**Figure 1: In-cylinder hydroxyl radical (OH*) and soot radiation at three different combustion phases (start of combustion, main combustion, post combustion) with different injection pressures ($p_i$) in operation with reference diesel fuel (B0) and di-n-butyl ether (DNBE).**

**Figure 1**. Segregation of indoor PM

**Patel K.S. / Pt Ravishankar Shukla-University** **Figure 2**. Emission fluxes of PM

## Segregation of Indoor Aerosol

### Background

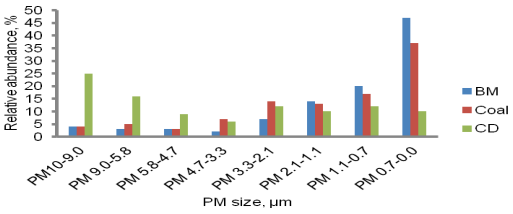
The biomasses, agricultural residues and charcoal are the primary source of domestic energy in developing countries. About half of the world households still use solid fuels such as wood, coal, cow dung and crop residues, ranging near 80% in the developing countries i.e. China, India and Sub-Saharan Africa. Indoor air pollution from biomass fuel is the 8th most important risk factor, responsible for millions of deaths. The smoke is a complex mixture of particulate matters (PM) including organic carbon (OC), elemental carbon (EC), silica, elements, various salts, etc. The indoor air pollution during household's combustion of solid fuels in developing countries causes several health problems [1-2]. Hence, in the present work, segregation and fluxes of the biomass, coal and cow dung(CD) particulates in 8 modes i.e. $PM_{10.0-9.0}$, $PM_{9.0-5.8}$, $PM_{5.8-4.7}$, $PM_{4.7-3.3}$, $PM_{3.3-2.1}$, $PM_{2.1-1.1}$, $PM_{1.1-0.7}$ and $PM_{0.7-0}$ in indoor environments are described.

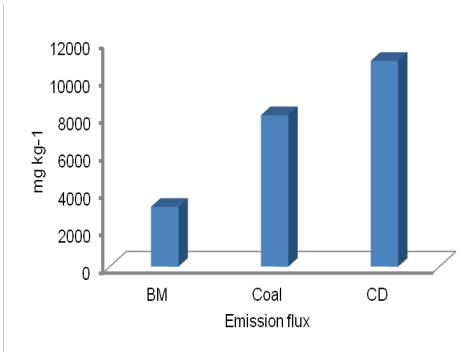
### Experimental

The 8-stages Anderson sampler was used for collection of the respirable particulate matters ($PM_{10}$) in January 2013. The $PM_{10}$ were collected simultaneously by using Partisol sampler on 47-mm quartz fiber filters (Whatmann, QMA) housed in the moulded filter cassettes. One blank filter was used to correct for the background values. The flux of $PM_{10}$ was determined by burning the materials in a closed chamber (0.5x0.5x0.5 $m^3$) equipped with the exhaust fan and UC Davis (USA) portable air sampler.

### Results and discussion

The concentration of $PM_{10}$ during burning $_{of}$ biomass, coal and cow dung in indoor environment lies < 5000 µg $m^{-3}$. The segregation of Biomass, Coal and cow dung particulate during burning processes is presented in **Figure 1**. The highest concentration of the ultrafine PM with the biomass and coal fuel was observed. The $PM_{10}$ emission fluxes for biomass, coal and CD were ranged from 3100 – 10700 mg $kg^{-1}$ with mean value of 7200±3900 mg $kg^{-1}$, **Figure 2**. The highest emission fluxes were observed with the CD fuel may be due to slow burning kinetics.




### Conclusion

The PM generated during burning processes of the fuels lie in coarse, fine and ultrafine modes. The higher fractions (>50%) of PM lie in the ultrafine modes in the case of BM and coal burning unlikely to CD. The highest emission fluxes of PM are observed with the CD burning. The recommended value of $PM_{2.5}$ and $PM_{10}$ in the air is 65 and 150 µg $m^{-3}$ (for 24 hour average), respectively. The PM generated during burning processes of the fuels was found to be several folds higher than the recommended values.

**Pielecha J. / Poznan University, Poland**

## Measurements of Particles Mass, Number and Size Distribution from Light-Duty Vehicles in Conditions of Variable Terrain Topography

The growing requirements concerning the natural environment protection and, in the consequence, the necessity of measurement exhaust emission from car vehicles also in the real traffic conditions, have resulted in taking into account the impact of area topography on the pollutants emissions from the vehicles. The previous research and results which were published in the literature refer to the flat area or the issues concerning topography impact on harmful exhaust components emission were omitted. However the significant differentiation of land, may affect on results of measurements of exhaust emission from vehicles.
The main purpose of the work was the analysis the vehicle's ecological parameters while driving on the roads with the changeable terrain shape, in real traffic conditions. The particular emphasis was put on the comparison the ecological parameters of the vehicles with diesel and spark ignition engines to the horizontal inclination of the axis of the road.
The work includes fully described research methodology which contains research objects, conditions of conducting particular emission tests stages and apparatus used. The measurement equipment made it possible to measure gaseous compounds and particulate matter - both in respect of the mass measurement, the particles number and size distribution. The research was aimed on the assessment of pollution emissions from the diesel and petrol fuelled vehicles. The first stage of research was carried on with use of the chassis dynamometer where for different values of road slope the European approval test (NEDC) was performed.
The second stage concerned research in the real traffic conditions with usage of the same research objects. Real traffic conditions have forced the usage of portable emission measurement system (PEMS) of harmful compounds. The car's pollution emission intensity measurement in the conditions of the changeable terrain was performed.
Comparison of the relative changes of road emissions depending on the terrain topography has shown that for small changes of the road slope, the most sensitive seems to be the road emission of carbon monoxide. Taking into account the increased slope values of the road, it turns out that the most sensitive for gasoline engines is emission of particulate matter, which is specific, first of all, to all diesel engines. Studies indicate that the increase of the slope values of the road to 10% causes on average twofold increase in the emission of harmful components of exhaust gases.
The obtained results confirmed significant effect of the diversified topography on the values of exhaust emissions from the vehicles. This influence turned out to be significant enough to justify the need of create approval test which includes coefficients correcting the road emission of pollutants in relation to the site topography.
The research was divided into several planes, which clearly shows, that in the tests of exhaust emissions being conducted in the flat area we get much less pollution emission, than it would result for vehicles used in various topography conditions.

**Rinaldo M. / Université de Bordeaux, France**

## Retention of Inhaled Fine and Ultrafine Particles by the Pleura and Accumulation in Black Spots

**Background**
In coal miners' lungs, coal and black dust often concentrate in macroscopic structures of the parietal pleura known as black spots. Pleural black spots are frequent in urban dwellers. Asbestos fibers also accumulate in these structures but very little is known about their content in other particles, especially ultrafine particles.
Methods
Normal pleural, anthracotic pleura and lung parenchyma samples of 10 patients selected from a previously published study were analyzed by transmission electron microscopy. The samples were digested in bleach and the particles retained by microfiltration were quantified by image analysis, then identified by energy dispersive X-ray analysis.
Results
Particle concentrations were in the same range in the black spots (16.2±26 $x10^9$ particles/g of dry weight) as in lung parenchyma (9.2±7.8$x10^9$p/g) and significantly higher than in normal pleura (1.1± 0.6 $x10^9$ p/g). There was no clear correlation between lung and pleural concentrations or between lung concentrations and areas of black spots. More than half of the particles were aggregates of ultrafine particles (65.3% in black spots, 54.1% in pleura) mainly composed of carbon. The mean diameter of particles was higher in the lung compared to the anthracotic and the normal pleura (lung: 623 ±129.1 nm, anthracotic pleura: 533±103 nm, normal pleura: 296±153 nm). Composition of the particles was similar in lung and black spots, although the percentage of mineral particles was higher in the latter (38.6±13.9% vs 27.5±12.5%). Exogenous ultrafine particles like iron, stainless steel and titanium were found in both samples.

**Conclusion**
This study demonstrates that the parietal pleura is able to retain inhaled fine and ultrafine particles that concentrate in black spots at concentrations that may exceed those in the lung. Whether these particles can induce adverse effects or potentiate effects of particles like asbestos fibers, which also concentrate in black spots remains to be established. Further investigations are required to understand the kinetics of the translocation of fine and ultrafine particles to the pleura and the consequences of their concentration in black spots.

**Robertson W.H. / CARB USA**

## Current Tailpipe PM Issues: A California Update

Combustion generated nano-particles remain an important control target for California in the near term despite efforts underway to foster widespread zero PM emission e-mobility options. The present transportation fleet, installed physical and fueling infrastructure and the commercialized vehicle technology base each contribute strongly to shaping the transport sector of California's airshed PM inventories. This existing transport technology mix is dominated by gasoline passenger cars and diesel heavy duty vehicles. Introduction of new engine/aftertreatment technologies to meet increasingly stringent GHG standards are challenging engine manufacturers and regulators alike as these technologies can present unique emissions profiles and exhibit particular applicability to specific duty cycles.
The California Air Resources Board (CARB) is continuing its concerted efforts to control tailpipe PM through ongoing programs aimed at reducing new vehicle emissions rates, ensuring those emissions rates remain durable over the useful vehicle life, and seeking the timely and effective addressing of defects via repairs and recalls.

The California Air Resources Board is addressing emergent light duty PM issues through the LEVIII process which is nearing its Mid-Term Review. CARB has conducted assessments of the current legislated gravimetric PM mass determination procedures in comparison with alternative filter sample collection methods and statistical procedures for evaluating compliance in the super low PM emissions regime of the 1mg/mi LEVIII phase-in. In addition CARB is evaluating alternative PM metrics for PM mass and particle number (PN) including Integrated Particle Size Distribution methods and particle number counting.

Multiple levels of activity are underway for heavy duty engine PM control. Research efforts are looking at PM emission variation with duty cycle including active regeneration emissions profiles and frequency. CARB has interest in whether PM certification procedures for new Off-Road engines are retaining their historic non-criteria emission benefits with the introduction into the California market of non-DPF Off-Road engine configurations. Regulatory work is being considered in the On-Road heavy duty sector to examine the role for Heavy Duty Inspection & Maintenance programs in facilitating aftertreatment in-field durability and insuring ongoing realization of PM reductions.

**Ruzal-Mendelevich M. / Ben-Gurion University, Israel**

## Controlling Nanoparticles Emission with Particle-Grouping Exhaust-Pipe

There is an increasing concern regarding the health effects caused by nano-size particle-emission. The nano-size particles weight is only 1-20% of the total particle mass while in number their percentage may be more than 90%. The nano-size particles emitted from vehicle exhausts might penetrate the respiratory system, diffuse to the blood stream, and conveyed to the brain. Those particles and their products can trigger oxidative stress, toxicity and inflammation in brain tissue.
Our method for reducing emission of nano-particles (Katoshevski et al., 2010) induces clustering and coagulation of particles by novel flow manipulation, leading to both a significant reduction in particle number as well as increasing particle size, and enabling further reduction in particle number by increasing filtration efficiency.

Four types of engines under different running conditions were tested: 1) A Ford transit 2L Diesel engine coupled to an engine dynamometer was examined under steady and transient conditions, 2) A heavy-duty MAN 10L vehicle installed with a Diesel engine was examined while mounted on a chassis dynamometer under steady conditions, 3) A light-duty Peugeot 1.5L vehicle installed with a gasoline engine was investigated with a chassis dynamometer under steady-state conditions and 4) A light-duty Citroen 1.5L vehicle installed with a gasoline direct injection was investigated with a roller chassis dynamometer under a standard driving cycle.
We present measurements of the particle number by using a Pegasor Particle Sensor (PPS) which allows measuring particles of down to 10 nanometers.
For each engine we have designed a specific particle-grouping exhaust-pipe according to its parameters. These include exhaust gas mass flow-rate, range of engine speed, valves' timing, and other relevant data. The parameters were introduced into the mathematical model [1], to optimize the pipe dimensions

**Test 1-**

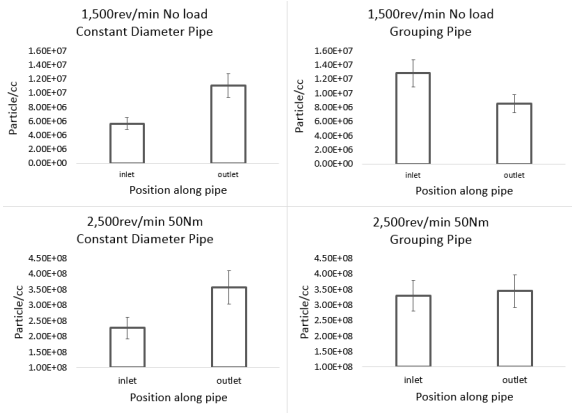



Figure 1-Particles average number per cubic centimeter for constant diameter (a) and alternating diameter (b) pipes at 1,500rev/min and no load, and for constant diameter (c) and alternating diameter (d) pipes at 2,500rev/min and 50Nm engine

**Test2-**

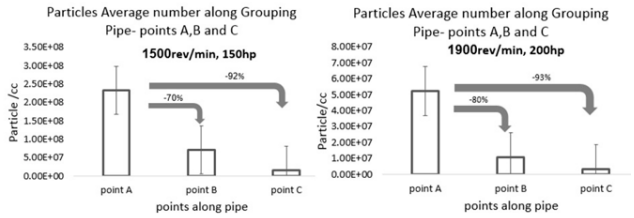



Figure 2- Average of particles concentration at 3 different locations along the exhaust pipe. At the alternating pipe entrance (A) and exit (B), and at the DPF exit (C).

**Seong Heeje / Argonne National Laboratory USA**

## Morphology and Crystalline structures of Engine-like Soot from KATECH's Soot Generator

Soot generators that simulate engine-like soot particles have been recognized to harness many fields in engine research, because they enable to control soot concentration, particle size, C-H ratios and other factors to mimic engine soot conditions. Accordingly, many institutes employ them for soot mass & number calibration, aftertreatment research, exhaust gas recirculation (EGR) fouling and soot sensor development. Most previous works were focused on similarity in soot emissions between actual engine soot and engine-simulating soot, in terms of primary particle size, aggregate size, and soluble organic fraction. However, detailed morphological and structural aspects, such as fractal geometry, nanostructures and crystalline structures, have been rarely examined. Based on our research of actual engine soot, engine-simulating soot samples were evaluated to understand their similarity and discrepancy to engine soot at several operating conditions.
A soot generator developed by KATECHwas used in this work. Atomized diesel fuel generated by nitrogen gas passes through the furnace, and particle size and concentration are controlled by adding nitrogen gas to atomized diesel fuel for dilution and furnace temperatures. For the current work, the atomizing gas flow rate and furnace temperature were kept constant at 4 L/min and 1300°C, respectively, while the dilution gas flow varied from 0 L/min to 3.5 L/min. Soot particles were collected on carbon-coated transmission electron microscope (TEM) grids to examine primary & aggregate sizes, fractal geometry and nanostructures by using TEM, and bulk soot samples were collected on Teflon filters for their carbon crystalline structures by using Raman spectroscopy.
TEM results showed that apparent aggregate shapes appeared to be chain-like structures, especially when the dilution flow rates were low. With increased flow rate, the number of less-opaque particles increased and spherical shapes of primary particles were observed to be non-round, which indicates that soot formation was delayed with short residence time. Nanostructures of particles by high resolution (HR)-TEM analysis revealed that when the dilution flow rates were relatively low, clear carbon fringe layers surround nucleus concentrically like typical engine soot (Fig. 1a). With increased flow rate, however, carbon crystalline structures are more like amorphous carbon (Fig. 1b), which was often observed for soot with high contents of alcohol in gasoline direct-injection (GDI) engines. Structural shapes of particle aggregates were statistically evaluated to indicate degrees of compactness of aggregates by fractal theory. Its fractal geometry is comparable to those of light-duty diesel soot and GDI soot. The change in fractal geometry was minor with varied flow rate. Raman results showed that carbon crystalline structures of engine-simulating soot are quite comparable to those of engine soot, although the former seems to contain more surface functional groups than does the latter. In the presentation, we will provide more Raman data of engine-simulating soot from a commercial soot generator using propane fuel for a detailed comparison.
Engine-simulating soot indicates that nanostructure, crystalline structure and other properties are appreciably affected by operating condition and these properties could be comparable to those of actual engine soot, depending on conditions.

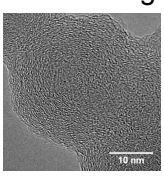
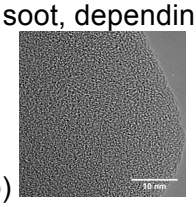
(a)  (b) 

Figure 1. HR-TEM image of engine-like soot particles: (a) Dilution gas flow rate = 0 L/min, (b) 3.5 L/min

**Stolcpartova J. / University of Liberec, Czech Republic**

## Particle Spatial Distribution in Suburban Area Celakovice: The Effect of Commuter Vehicle Traffic.

This work investigates spatial distribution of particles in a small city Celakovice situated 15 km north-east of Prague, 4 km far from the closest highway. Inhabitants commute daily to work to Prague by public transportation and many of them by car. This situation is typical for the most small cities and satellites around larger cities. The aim of this study was to determine the effect of the traffic volume peaks on the particle concentration near main roads and its effect on farther dwellings.

For measurement, two mobile sets of instruments were employed. Both includes online particle classifier with size-resolved measurements of particles in the 5-500nm in diameter (Engine Exhaust Particle Sizer$^{TM}$, Model 3090, TSI), mounted, along with batteries, GPS and other accessories, on a hand cart. Additionally one set was equipped with a condensation particle counter (UF-CPC 200, Palas) which counts particles from 5nm to 10µm. Both instruments sets worked simultaneously, one along the main road, the second roughly 150 m from the road. Later after morning traffic peak both instruments sets were operated far from the road. Measurement was carried out in two working days, 31$^{st}$ January and 3$^{rd}$ February, 2015.

The average concentrations of particles in the 5-100nm size range ranged from under or around $2x10^4$ #/cm$^3$ in the vicinity of the road with peaks around $4x10^4$ #/cm$^3$ after passage of heavy vehicles (buses and trucks). Episodes with very high concentrations were also captured after passing of high emissions vehicles as a tractor and/or an old car in poor technical condition ($1\text{-}5x10^5$). One hundred fifty meters far from the road, particle number concentrations decreased and ranged under or around $1.5x10^4$ #/cm$^3$. After morning traffic peak the concentrations were stabilized between $1.5\text{-}2x10^4$#/cm$^3$ (results from morning measurements are shown in Figs 1-3). After 10:00 concentrations gradually decreased to a concentration about $10^4$#/cm$^3$ at midday (3$^{rd}$ February), and $7x10^3$#/cm$^3$ (31$^{st}$ January). Afternoon traffic peak measurement (only 3$^{rd}$ February) showed similar results as morning peaks. Total particle counts from the size distributions and measured by the condensation counter correlated reasonably well when the classifier was not moving.

Concentrations along main road were elevated in comparison with places at least 150m far from the road; however, the difference was relatively small. Concentration between morning and afternoon traffic peaks ($7x10^3$ to $1.5x10^4$#/cm$^3$) was elevated in comparison with Prague background concentration, $7.3x10^3$ #/cm$^3$(Rimnacova et al., 2011). Although concentrations followed daily pattern corresponding to traffic intensity, the main road did not seem to be the main source of measured particles in areas 150 m from the road.

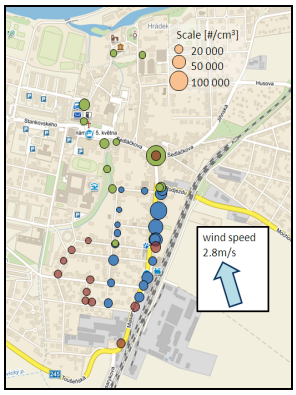



**Figure 1**Particle number concentrations 31$^{st}$ January; simultaneous measurement at 7:30-8:00 blue; 8:00-8:20 red; 8:20-9:00 green

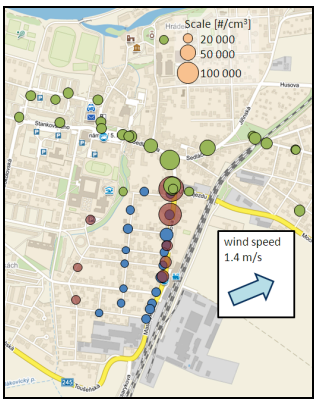



**Figure 2** Particle number concentrations 3$^{rd}$ February; simultaneous measurement at 6:45-7:20 blue; 7:20-7:35 red; 7:35-9:00 green

**Suarez-Bertoa R. / JRC Italy**

## Ammonia Exhaust Emissions from Euro 5 and Euro 6 light Duty Vehicles

Particulate matter has been related with impoverishment of the urban air quality and also to have an impact on climate due to their capability to scatter solar radiation back to space (Forster et al., 2007) and because they can act as cloud condensation nuclei, modifying cloud properties, producing an increase of droplet number concentration and a decrease of droplet sizes as well (Twomey 1991). It has been reported that 40% of the total $PM_{2.5}$ is formed by secondary inorganic compounds, namely ammonium, nitrate and sulfate, for some European cities (Sillanpää et al., 2006) and that ammonium account for up to 17% of the total mass of $PM_{2.5}$ in the South Coast Air Basin (Kim et al., 2000). When these compounds are transported to remote areas, their deposition also leads to hypertrophication of waters and acidification of soils with negative effects on nitrogen-containing ecosystems (Sutton et al., 2008).
Ammonium nitrate and ammonium sulfate are formed by reaction of nitric and sulfuric acid with ammonia ($NH_3$) (Pope et al., 2002). Vehicles are considered to be an important source of $NH_3$ in the urban environment and may be comparable to natural source emissions in certain urban areas (Livingston *et al.* 2009). Up to now, traffic-related $NH_3$ has been considered to be mainly produced in the Three-Way-Catalyst of gasoline light duty vehicles. However, with the introduction of new after-treatment technologies such as SCR and LNT, diesel vehicles will soon become sources of $NH_3$. Therefore, it is crucial to quantify the $NH_3$ emissions from vehicles exhaust in order to develop effective air quality control strategies. The National Emission Ceilings Directive 2001/81/EC (NECD), the Gothenburg Protocol under the United Nations Convention on Long-Range Transboundary Air Pollution (LRTAP Convention) (UNECE 1999) and the IPPC Directive (2008/1/EC) aimed at reducing the emissions of several compounds, including $NH_3$. In order to meet the National Ambient Air Quality Standard (NAAQS) for $PM_{2.5}$, the US Environmental Protection Agency (EPA) required regulating ammonia emissions in the case that a State or EPA itself demonstrate that ammonia is a significant contributor to $PM_{2.5}$ formation in an area.
Here we present $NH_3$ emission factors obtained for a series of light duty vehicles equipped with last available after-treatment systems at the European Commission Joint Research Centre Ispra, Italy, in the Vehicle Emission Laboratory (VELA) and over the new Worldwide harmonized Light-duty vehicle Test Cycle (WLTC). $NH_3$, among other gases, was monitored online at 1Hz acquisition frequency by a High Resolution Fourier Transform Infrared spectrometer (FTIR). The raw exhaust was sampled directly from the vehicles' tailpipe with a heated line at 190°C. The tests were performed at 23 and -7 °C. The results show that ammonia emissions are considerable for the fleet at the two studied temperatures.

**Talebizadeh P. / Amirkabir University Iran**

## Investigation of diesel particle deposition in tubes

There has been a continuous increase in the number of diesel engines operating in both stationary and mobile applications, due to their lower operating cost, higher thermal efficiency, longer durability, and their lower hydrocarbon (HC) and carbon mon- oxide (CO) emissions. However, these engines emit higher amount of NOx and particulate matters (PM) than gasoline engines. Moreover, exhaust emission regulations have become much more stringent in recent time and there is still considerable concern that unregulated pollutants are having a deleterious effect on human health and the environment generally. Up until now, several technologies have been applied for PM removal from exhaust gases. Diesel oxidation catalysts (DOC), diesel particulate filters (DPF) and fuel borne catalysts (FBC) have been considered for DPM, HC and CO control in automobile and stationary engines. Since the emissions of HC and CO from diesel engines are low, these technologies are focused on PM reduction. Most of these technologies are related to the reduction of PM mass while neglecting the number of particles

Plasma treatment reactors have recently been developed for the elimination of diesel particulate matter regarding the reduction of both particle mass and number. While such systems have been demonstrated to be effective, challenges remain due to high specific energy consumption and the possibility of generating particles under some operating conditions. The role of the plasma itself is obscured by the phenomenon of particle deposition on the surface of the reactor. Lagrangian particle tracking provides an effective method for simulating deposition of such nano-particles (and micro-particles) because it accounts for particle inertia effect and Brownian excitation. In this paper, the deposition of nano-particles in annular tubes under laminar condition is studied using a Lagrangian particle tracking method. The role of particle diameter, reactor length and flow rates are examined. The results show good agreement between the calculated deposition efficiency and the analytic correlations in the literature. Furthermore, the results show that for nano-particles with a diameter more than 40 nm, the calculated deposition efficiency using the Lagrangian approach is less than that of the Eulerian approach. This may be attributed to statistical error or the inertia effect. It is shown that some particle reduction previously ascribed to plasma treatment had ignored contributions fromsurface deposition.

**Tochino Shigemi / Horiba Japan**

## Repeatability study of detection efficiency and linearity during CPC calibration using Emery Oil Aerosol

The Particle Measurement Programme (PMP), organized under the auspices of the Working Party on Pollution and Energy (GRPE) of the United Nations Economic Commission for Europe (UN/ECE), developed a particle number (PN) measurement procedure resulting in the adoption of UNECE Regulation 83. This measurement procedure defines a specification for the Particle Number Counter (PNC) most commonly met by utilizing a Condensation Particle Counter (CPC). This CPC needs to be calibrated annually as described in Regulation 83. In March 2015 the description of the CPC calibration procedure against an Aerosol Electrometer (AE) or a reference CPC was complemented by the introduction of ISO 27891.
Two of the requirements already mentioned in the Regulation 83 are related to the counting detection efficiency against the reference instrument as well as the linearity at different concentrations across the CPC measurement range. It is well known that the CPC detection efficiency depends on the aerosol material used for the calibration. Poly-alpha-olefin (PAO) is a widely used material with high detection efficiencies for the CPC to satisfy the regulation requirement. PAO aerosol can be produced by the electrospray ionizer method, but with this generally skilful method it is difficult to generate very small aerosol particle sizes such as 23 [nm] in a constant concentration over a long operation time. This might lead to a poor repeatability of the CPC calibration in terms of the counting efficiency and the linearity measurement. With the implementation of additional uncertainty calculations in ISO 27891 it is urgently required to maintain a stable aerosol generation to achieve a reliable calibration procedure with low uncertainties.
In this paper, we carried out some improvements on the aerosol generation using the electrospray method to overcome this task. We observed that one of the obstructive factors for a stable particle generation is nanoscale aggregation in the sample liquid which can be prevented by our unique sample preparation.

**Tonegawa Y. / JARI Japan**

## Development of Tire Dust Emission Measurement for Passenger Vehicle

Non-tailpipe emissions such as tire dust should be contained in PM2.5, but those emission data are lacked, because measurement methods for tire dust are not established. In this research, we developed a measurement method for tire dust emissions using a testing vehicle to measure road friction. The tire testing vehicle having 5th wheel with 6-component force measuring system was used to generate tire wear particles. Sampling system for PM2.5, 10 was constructed to collect tire wear particles. Tire dust measurement test was conducted on a test course at JARI. The test vehicle was reciprocated driving during the straight section of the course. We also investigated tire dust measurement with an indoor drum tester.

Tire wear particles generated by the indoor drum testing system were different from particles generated by the tire testing vehicle. Tire dust of almost size of mm, like eraser dust, were observed around the drum testing equipment. Tire surface was rough after experiment, because tire dust should be re-attached during test. The shapes of particles in the road test were spherical, and the sizes of particles were about 10μm. In laboratory test, the shape and size were much different compared to the road test ones. Therefore, Real environment testing is required in order to correctly evaluate tire dust emission, because tire dust is generated by interaction with road surface.

In the road test, tire dust emission rate of PM2.5 was increased with an increase of acceleration. However, tire dust emission rate was less affected by the change of vehicle spleed. From the result of road testing, emission factor of tire wear particle was calculated applied to JC08 test cycle. Tire dust should be significantly emitted when acceleration is changed at high speed. PM2.5 emission from tire dust was calculated as 3.7 mg/km. From the estimated value calculated from the JC08 test cycle, 3% of whole tire wear is emitted to atmospheric environment by tire wearing. Therefore almost tire dust should be remained on road surface.

**Topp M. / HUG Engineering AG, Switzerland**

## Exhaust Gas Purification System for Ground Power Units (GPU)

Exhaust Gas Purification System for Ground Power Units (GPU) – mobicleanR e-Power. Hug latest innovation to reduce aggressive fine dust emissions with the aim to improve ground staff health protection and environment improvement
For remotely parked aircrafts the Hotel load (on-Board power) is supplied by a so called Ground Power Unit (GPU). This GPU is fitted with a diesel engine connected to an alternator and surrounding sub-assemblies such as fuel supply, cooling, electronics and exhaust silencer.
In the course of further reduction of emission limits, in that case particulate emissions at the Zürich airport, the city of Zürich made a requirement to retrofit about 15 GPU with a modern exhaust treatment system.
Caused by a rather low load operation of the diesel engine of the GPU a particle filter needed to be fitted with an active regeneration system.
In the first phase two prototypes where fitted with an exhaust treatment system. One GPU with a mobiclean R advanced system, comprising a Pre-Oxidation filter and a diesel particle filter. To ensure regeneration even in low load operation associated with very low exhaust temperatures an electric exhaust heater (10 KW) is mounted in front of the CRT system.
A second prototype was fitted with a SCR System. This system was derived from the mobiclean R13 ASCR system and should prove the NOx saving potential.

A common solution for all airport GPU`s

- For generators exceeding 65 kVA
- Active electric regeneration for engines with low exhaust gas temperatures
- Extremely low fuel consumption, Full stream regeneration in 15 minutes
- MobicleanTM R e-power reduces more than 97% of the soot particulates within the exhaust gas
- No wear and tear parts
- No limit regarding the sulfur-content in the carburant
- Insulation and hood for heat protection and protection of environmental influences
- Voltage heater 200 VAC 400 Hz
- Electric Power Generator: 65 - 90 kVA and 90 - 120 kVA
- Engine Power: 85 - 120 kW and 120 - 150 kW
- Temperature at low power: 180 °C
- Temperature during regeneration: 530 °C
- Filter type: R20 basic filter
- Voltage controller 24 VDC
- With soot load calculation of the DPF
- Average regeneration time: approx. every 30 hours
- Safety routine: safe against engine overload & start of regeneration only under engine load
- Regeneration time: approx. 15 min.
- Service Intervals: 1.000 – 2.000 hours (more frequent regeneration indicated by alarm)

Testing:

- 15 units are already delivered to Swissport and are in operation.

**Tritscher T. / TSI Germany**

## Laboratory and Field Measurements of Solid Particle Number with the Nanoparticle Emission Tester (NPET)

The negative impact of emissions from engines and almost any combustion process on human health and the environment is well-known. In recent years, the combination of modern engine technologies, efficient aftertreatment and new emission standards has led to drastically lower emission levels. In the case of diesel engines, the introduction of diesel particulate filters (DPF) lead to a significant reduction of the particulate matter emission. DPFs can remove greater than 99% of particulate matter from the exhaust when operating properly. Nonetheless conventional methods defined to test particle emissions fail at such low levels as they are aimed at determining the mass of the particles. This led to particle number (PN) measurement as the method of choice for low particle emissions. With emission standards like Euro 5b/6 or Tier 4, solid PN concentration has become a proven and widely accepted metric for researchers and regulators to determine compliance with emissions limits. Existing field-based methods to measure engine PM emissions are typically opacity based and not sensitive enough to measure the greatly reduced particle concentrations downstream of a DPF (Mayer, 2004). Recently, Switzerland as the first country worldwide introduced a legislation aimed at in-use compliance testing of construction machinery DPFs.

A portable instrument capable of measuring the total number of solid particles from combustion sources including construction machinery DPFs has recently been developed. The Nanoparticle Emission Tester (NPET, Model 3795, TSI Inc.) was first introduced at the 18th ETH conference one year ago (Horn et al., 2014). This field instrument consists of a built-in sample dilution and conditioning system that prevents condensation and removes humidity as well as coarse particles from the sample. Volatile particles are eliminated first by a built-in catalytic stripper (CS) before the number concentration of solid particles is subsequently measured using an isopropanol-based condensation particle counter (CPC). The NPET is capable of measuring number concentration from less than 1,000 up to 5,000,000 particles per $cm^{-3}$ (Bischof, 2015). This emission tester provides reliable measurements far below the detection threshold of opacimeters and has been certified by METAS as testing instrument compliant with Switzerland's new emissions regulation 941.242. The NPET is well suited for in-use conformity and maintenance testing of diesel-powered, non-road mobile machinery (NRMM) as well as vehicle inspection and maintenance programs. It can reliably determine if the installed DPF is working properly or if it is damaged and needs to be replaced.
The characterization of the NPET's performance in comparison to existing technology, as well as results from in-use emission testing in the field will be presented. Figure 1 shows one example from laboratory measurements. Here the NPET's concentration linearity was compared to a CPC (Model 3772, TSI Inc.) after a Rotating Disk Diluter (Model 379020A) operated at 80°C with a constant dilution ratio of 60:1. In-use performance of the instrument was evaluated by measuring the number concentration of solid particles emitted by several vehicles on and off-road. During these tests the condition of the aftertreatment system of the vehicle under test was determined.

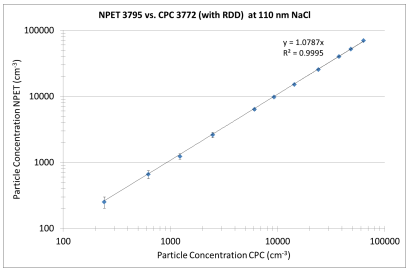



Figure 1: Linearity of NPET 3795 and CPC 3772 with RDD for monodisperse salt aerosol.

**Tsakis A. / CPERI/CERTH Greece**

## Particles Emitted During Braking – A preliminary study

The objective of this work is to initiate research at our laboratory on the assessment and characterizations of particle emissions from brake wear. To this end measurement campaigns with a vehicle (Mobile Laboratory, MOBILAB) running on a chassis dynamometer. were realized. Brake particle emissions were measured by employing a custom sampling arrangement, with two sampling points, at the front and rear sides of the brake pad / brake caliper system. A CPC and an ELPI was used to obtain particle concentrations and size distributions. Measurements were conducted at constant wheel speed motoring mode (no engine running) of the dynamometer at 40, 60 and 80km/h and also on three test cycles (NEDC, Artemis, FTP). A preliminary assessment of the data indicates that there are distinct emission events of nanoparticles during braking. A parametric study is underway but it is already evident that brake wear particles can be assessed and differentiated.

**Vojtisek-Lom M. / Technical University Prague, Czech Republic**

## Real Driving Emissions from a Diesel-Hydraulic Rail Vehicle

The progression of emissions reduction interest from on-road to non-road engines brings about the need to evaluate their emissions, both under standardized and real driving emissions. Diesel-electric locomotives are typically tested by diverting the electric power generated by the diesel engine from traction motors into a load bank, and by using a mobile laboratory to measure emissions at steady-state points. With a diesel-hydraulic locomotives and motorized units, this is often not possible.

In this work, real driving emissions from a diesel-hydraulic motorized car with a twelve cylinder, 27-liter turbocharged Caterpillar 3412 engine were investigated during its regular passenger train service. The non-active isle of the engine compartment was fitted with a miniature battery-powered portable on-board emissions monitoring system, sampling from the exhaust system into multiple analyzers measuring the concentrations of CO, CO2, NO, NO2 and particulate matter. Engine was fitted with rpm and intake air pressure and temperature sensors, based on which intake air flow was calculated and used to drive a proportional filter sampling system for gravimetric measurements of PM mass emissions. The car was operated on local and express Czech Railways services, both alone and pulling 1-3 non-motorized cars.

The measurements provided valuable insights into the reality of on-track real driving emissions measurements of rail vehicles: In the absence of the vehicle modifications, given various safety and operational constraints, the instruments are essentially confined into a relatively small space in the engine compartment, where they have to operate unattended and using their own power. Also, direct measurement of exhaust flow is difficult, and sampling either needs to be restricted to steady-state operation, or rely on compact exhaust flow inference setup.

Preliminary results suggest that such measurement is challenging but feasible. Even with an older engine with 1 million of km accumulated, the particle emissions were relatively low, on the order of 1 mg/km per passenger at the declared maximum occupancy. Compared to prescribed locomotive test engine operating conditions, excess particle emissions were generated during transients, however, transients were modest compared to on-road vehicles.

Authors thank the Czech Railways, Prague-Vrsovice depot, for allowing the measurements and for technical assistance. Measurements were funded by EU LIFE+ program, project LIFE10 ENV/CZ/651 – MEDETOX, Innovative methods for monitoring diesel exhaust toxicity under realistic urban operating conditions. M.V. acknowledges support from the European Social Fund project “Support of inter-sectoral mobility and quality enhancement of research teams at the Czech Technical University in Prague” (CZ.1.07/2.3.00/30.0034).

**Woodburn J. / BOSAL Poland**

## Comparisons of solid particle emissions from a range of vehicles tested over 3 driving cycles

Particle emissions from vehicles continue to cause concern and are increasingly subject to legislative limits, most notably in the EU, where soon over half the passenger cars sold will be subject to limits for the mass (PM) and number (PN) of particles emitted in the exhaust gas. In the USA, all passenger cars must meet limits for PM. These limits are set for testing under laboratory conditions according to the local test procedures. In Europe (and elsewhere) the New European Driving Cycle (NEDC) was used. In the USA, PM limits apply to the US test cycle (FTP-75). A new global harmonized driving cycle has been developed, known as the WLTC. In this study, a range of passenger cars with both petrol and Diesel engines were tested over the three aforementioned test cycles. The European methodology was used to measure PM and PN (particle counting of solid particles only): a dilution tunnel was used, together with TX40 Teflon-backed filters and a condensation particle counter with an evaporation tube operating at 350°C.
Some brief considerations of the three driving cycles are offered, together with results and analysis. Emissions results are distance-specific [/km] – and so the length of the three driving cycles was also considered. While the PM results varied somewhat from vehicle to vehicle, there was an overall tendency for the NEDC to generate the lowest results, and the WLTC the highest. The PN results also varied, but overall PN results from the WLTC were found to be the lowest. Results were also analysed phase-by-phase – legislative PM measurements either have a resolution of 1 result/phase or 1 result/test; in contrast, particle number results can be analysed at a frequency of 1Hz, enabling investigation of specific points of the operating cycle. An analysis was made of pull-away events, very low and very high speed and periods of acceleration, to assess the contribution to total PN emissions over the three test cycles.

**Zhou J. / PSI Switzerland**

## Ambient Air Measurements of Reactive Oxygen Species (ROS) in Beijing and Bern

In this study, we use an on-line reactive oxygen species (ROS) analyzer to detect and compare ROS in the particle phase of ambient aerosol in different urban areas. Bern (Switzerland) and Beijing (China) were chosen to assess the effects of ambient particles especially ROS on human health. We developed this method further according to King et al. and Fuller et al. with a time resolution of a few minutes [1, 2]. ROS are measured based on the fluorescent detection of dichlorofluorescein (DCF).
In presence of horseradish peroxidase 2',7'-dichlorofluorescin (DCFH) is oxidized to fluorescent DCF and subsequently detected using a fluorimeter. The detection limit was estimated to be ~1.2 nmol $m^{-3}$.

Our first ambient measurements were performed at the Institute of Anatomy at the University of Bern during winter time. At the same time cell exposure experiments using fully differentiated human bronchial epithelia were performed. Particle mass concentrations of particulate matter smaller than 2.5 µm ($PM_{2.5}$) were quite low and as the ROS content of $PM_{2.5}$ in ambient particles was below the detection limit. Therefore the versatile aerosol concentration enrichment system (VACES) [**3**] was employed during ROS measurements. Using the VACES the concentration of $PM_{2.5}$ could be enriched by up to a factor of 25 and a diurnal variation of ROS could be recorded. Additional measurements including a scanning mobility particle sizer (SMPS), a condensation particle counter (CPC), an aerosol chemical speciation monitor (ACSM) and an aethalometer gave additional information on the size and chemical composition of $PM_{2.5}$.

In collaboration with the Institute of Earth Environment, Chinese Academy of Sciences, we participated in field measurement campaigns in Beijing. We were able to measure ROS directly in ambient particles during haze days.

The ROS contents of Bern and Beijing will be presented, giving a deeper insight in the diurnal variation of ROS and the behavior during haze events in Beijing.

This work was supported by the Swiss National Science Foundation (407040_153970/1) and the China Scholarship Council (CSC).
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[2] King, L.E. and Weber, R.J. (2013) *Atmos. Meas. Tech.* **6**, 1647–1658.
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**Zöllner C. / LTTT Bayreuth Germany**

## Comparison of Soot Deposition in Diesel Particulate Filter Segments Operating with Diesel Fuel and Biodiesel

The removal of soot from diesel exhaust is necessary due to protection of the environment and human health. To meet the strict emission standards for diesel engines of passenger cars an additional exhaust aftertreatment is essential. Diesel particulate filters (DPF) are established devices to remove emitted particulate matter from diesel exhaust. But the accumulation of the soot in particulate filters influences filter back pressure and therefore engine performance and fuel consumption. The characteristics of the deposition and distribution of particulates within the filter are determined by a variety of parameters. The use of different fuels is one of them.
Within the framework of the present study, the influence of different fuels on filter backpressure and soot distribution in a particulate filter segment was analyzed. Therefore a system on the exhaust line of a production diesel engine operating with different diesel fuels (reference diesel (B0), biodiesel (B100)) was developed to collect soot samples after diesel oxidation catalyst on tissue filters and on real diesel particulate filter segments. The engine was operated in a steady state mode. For the comparability of the different diesel fuels due to the different heating values the engine was adapted to the same power by adjusting the injection quantities. Soot loading on tissue filters was realized by using a filter holder made of stainless steel. The particulate filter segments were placed in a stainless steel reactor. Space velocities were controlled by a mass flow controller. Before the loading procedure filters were treated in a high temperature furnace to avoid influences of water and hydrocarbons. Tissue filters as well as particulate filters were loaded up to a certain amount of soot under isothermal conditions. During the soot loading procedure the differential pressure was recorded. Soot thickness in the particulate filter segments was investigated by means of a scanning electron microscope combined with an energy dispersive X-ray system. The density of the soot was analyzed with a gas pycnometer. Particle size distribution was measured with a Scanning Mobility Particle Sizer.
The results show significant differences between the different fuels concerning particle size distribution and differential pressures during the loading procedure of tissue filters and DPF segments (figure 1). The deposition of soot inside the particulate filter segments is not uniform with a thicker soot layer at the beginning and at the end of the inlet channels. Loading with biodiesel takes much longer until a comparable amount of soot was reached. Comparing the soot accumulation of the different fuels the thickness and density of the soot layers in the particulate filter segments show distinct differences.
The experiments regarding soot cake thickness and its density of trapped soot in the particulate filter segments generated with the different diesel fuels provide fundamental input values for modelling the deposition behavior of soot. Furthermore, the study gives important information for the development of new regeneration strategies of trapped biodiesel soot in diesel particulate filters.

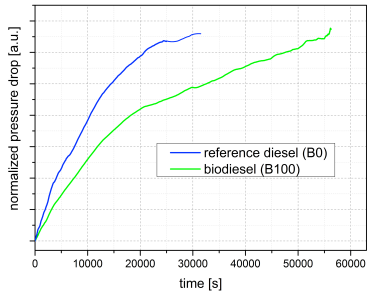


Figure 1: Development of normalized pressure drop of particulate filter segment for soot loading with reference diesel and biodiesel