20th ETH Conference on Combustion Generated Particles

Zurich, June 13th – 16th, 2016

Book of Abstracts Poster A - M

Status: 13. Mai 2016

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Volatile classification of diesel emitted particulates measured by SMPS and multi-wavelength PhotoAcoustic Spectrometer (4λ-PAS)

Diesel emitted particles have versatile chemo-physical properties that strongly depend on fuel type and engine operational conditions as well. Moreover, they are in a thermal equilibrium state with their local ambience during their short scale evolvement periods in the tail pipe system and their long scale quasi steady-state condition in their ambient residential interval as well. Vapour-particle partitioning can result in different particulate mixing states such as core-shell or fractional arrangements of volatile and non-volatile as well as homogenous mixing of abundant non-volatile compounds. Although the mixing state of ambient particulates is a key issue both in climate forcing and also in air quality studies, investigation of the mixing state dimensions of diesel particulate matter are limited and restricted mainly to the size distribution measurements yet. Therefore, comprehensive investigation of the mixing state dimensions of the measured diesel exhaust particulates properties using commercial and state-of-the-art instrumentations is an actual and key issue in many disciplines.

In this study, the raw engine out emission of a four cylinder EURO IV PC diesel engine (2 litres turbo charged, common rail injection system) fuelled with commercial diesel acc. to EN 590 including biofuel (FAME) in a regulated amount (7% - B7) and the FAME free version of that (B0), operated at three characteristic engine conditions (rev/torq) was investigated. Posterior temperature treatment of the sample was applied to remove the volatile fraction of the exhaust by an improved low-flow thermodenuder (TD) unit designed for these specific sampling conditions. The number concentration and the size distribution of the temperature treated aerosol sample was measured by a single mobility particle sizer (SMPS, Grimm Aerosol Technik GmbH) while the absorption response of the sample was measured by our recently developed state-of-the-art multi-wavelength photoacoustic spectrometer (4λ-PAS).

We experimentally demonstrated here that the FAME content can substantially modify the characteristics of emitted particles even in its relatively low amount in the regulated domain. We also revealed and quantified the temperature dimensions of both size distribution and absorption response of the emission. We further experimentally proved that the absorption data does not only serve additional and independent information of the emission characteristics, but can refocus and widen the interpretation of size distribution data. Finally, we confirmed that multi-wavelength photoacoustic spectrometer is a powerful tool for in-depth characterisation of diesel emission and its mixing states, opening up novel perspectives in emission based fuel and engine developments.

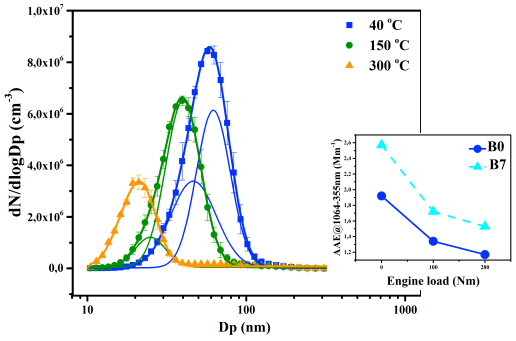

Figure 1. The size distribution in the function of sample temperature and AAE (Aerosol Angström Exponent (inset)) in the function of engine load. The square symbol represents the measured data, while the coloured lines represents the fitted curve and the related mode structure respectively.

Arndt Michael / AVL List

Optimizing a photoacoustic soot sensor for the measurement of ultra-low soot concentrations in real-world exhaust

Photoacoustic soot sensors are capable of measuring very low concentrations of soot by using the light absorption of the black carbon in order to generate an acoustical signal (pressure waves). Measuring soot concentrations of 1 µg/m3 (or even lower) is easily possible under well controlled conditions. When engine exhaust should be analyzed for soot content, the chemical composition of the gas can influence the precision of the measurement. Changes in the gas composition affect the acoustic properties of the gas (sonic speed). This can show up as a drift in the zero value as well as a shift in signal intensity.
Distortions by cross-sensitivities can be minimized by selecting the appropriate light source, whereas acoustical effects can be reduced by proper dilution. As a consequence the impact of these effects is negligible in most applications.
In some cases where a very high sensitivity is required, a proper dilution might not be desirable or possible. Conducting a so called “zeroing with filtered exhaust” efficiently eliminates disturbances caused by cross-sensitivities and acoustical effects. However, this method adds complexity to the automation of the application. In addition it only yields perfect results when the exhaust composition stays constant, which is not always the case.
In order to overcome these issues a novel method for real-time compensation of the mentioned distortions was developed. It contains a fast compensation for the cross-sensitivity to water vapor as well as smart algorithm package for eliminating acoustical effects. The method makes use of the fact that changes in the sonic speed manifest as a shift in the resonance frequency of the photoacoustic resonator system. The laser light source is modulated at the characteristic resonance frequency of the cell in order to obtain best signal amplification. The modulation frequency of the laser gets adjusted in real-time in order to keep the system at the resonance maximum. This is done by analyzing the phase angle of the standing acoustical wave. If the signal intensity is not high enough to generate a clean signal for this purpose, an additional acoustical wave at a different frequency is induced by an internal loudspeaker. This additional signal is analyzed in parallel to the main signal. Thereby a correction of the modulation frequency is calculated in real-time. The processed measurement signal only consists of the main frequency, any other acoustical waves are removed by synchronous demodulation.
Tests have shown that the accuracy of the recent version of a widely used photoacoustic instrument, the AVL Micro Soot Sensor plus (MSS+), could be improved significantly by applying this method.

Avdesh Bhardawaj / Indian Institute of Technology Delhi

A study of ultrafine particle related health effects due to biomass burning for cooking in North Indian regions

The health effects of aerosols have been a topic of much interest and research in recent times [Brunekreef and Holgate, 2002; Foster and Kumar, 2011; Patankar and Trivedi, 2011; Langrish and Mills, 2014; Greenstone, 2015; Newby et al., 2015]. 5.5 million people die prematurely worldwide each year due to fine and ultrafine particles (UFP) [AAAS, 2016]. Indoor and outdoor air pollution are major causes of mortality in India [Lozano et al., 2013; Vos et al., 2015]. Even in these modern times, a large section of Indian rural and semi-urban population depends upon biomass burning as a source of fuel for cooking [Ventakraman et al., 1999], which can cause the formation of UFPs [Hata et al., 2014]. These particles can travel from various entry sites such as dermal, inhalation, oral or olfactory route apart from ingestion of food having UFP deposits. The deposition of inhaled particles in the human respiratory tract is dependent upon the partricle diameter [Buzea et al., 2007] and UFPs find it easier to penetrate deep into the human system. Once into the human respiratory tract, they can translocate to other parts of the body enabling them to enter deeper into lungs, causing both acute and chronic adverse health effects such as asthma, cardiovascular and ischemic heart diseases due to systemic inflammation [Smith et al., 1993; Smith et al., 2003; Oberdorster et al., 2005; Pope 2015]. Even in India particulate matter has been linked to a range of acute and chronic morbid effects and premature mortality [Guttikunda and Goel, 2013; Pyne et al, 20014; Rumana et al., 2014]. In the present study sampling for measurement of mass and number concentrations of the aerosol due to biomass cooking in areas near Delhi, India was done using wide range aerosol spectrometer i.e. WRAS [with 41 channels from 10 nm to 35 µm range]. Correlations were made with health effects using standard health questionnaire and background information on the chemical characterization of the aerosols as well as ECG holter monitoring and spirometry for selected subjects. It is intended to link the health effects due to biomass burning for cooking with their mass and number concentrations to offer scientific evidence for suitable policy formulation and implementation for such cases to minimize adverse health effects and improve well being of the people.

Key words: Biomass, cardiovascular illness, ECG, respiratory illness, spirometry, UFP, WRAS.

Bailey Brett / Illinois Valley Holding Comp. IVHCO

Global Non-Thermal Active SCR/DPF Emissions Reductions Technology Volkswagen Jetta Demonstration

Cool Particulate Regeneration™, CPR™ demonstration project on a 2011 Volkswagen Jetta fitted with a Lean NOx Trap will be presented. Lean NOx trap operation requires a diesel engine to operate under rich air/fuel ratio conditions for a few seconds approximately every five minutes. Rich air/fuel ratio combustion in a diesel engine generates increased particulate matter emissions requiring additional particulate filter regenerations. The increase in inefficient thermal regeneration frequency adversely affects the inherent efficiency advantage of the diesel engine.

CPR efficiently removes the particulate matter utilizing waste braking energy and then recycles the particulate as a fuel to be combusted in-cylinder. Particulate into Power is the introduction of the particulate matter into the diesel fuel for efficient recycling. The current approach of introducing the particulate into the fuel will be discussed. Efficient recycling of particulate matter allows improved performance and drivability as rich air/fuel ratios providing improved power

India moving to Euro VI emissions regulations effective in 2020 is a bold step toward cleaner air for the country. The challenges for implementing Euro VI emissions in India will be many, but the need for Ultra Low Sulfur Diesel (ULSD) and whether their customers will want or be able to pay the premium for Euro VI emission capable vehicles are critical issues. CPR is expected to allow low cost mechanical fuel injected engines, still available in India, to meet Euro VI emissions with a single oversized Vanadium Pentoxide (V_2O_5) catalyzed particulate filter. The oversized particulate filter is enabled by the removal of thermal regeneration and will additionally allow for simplified urea control.

Although many developing countries have high air pollution, the implementation of internal combustion engine particulate filter aftertreatment has been delayed due to the unavailability of Ultra Low Sulfur Diesel, ULSD fuel. These developing countries require an efficient, low owning and operating cost, and robust Diesel Particulate Filter, DPF regeneration system, such as CPR, that can operate on high sulfur fuel. Instead of replacing legacy vehicles in developed and developing countries, they can be retrofitted in the market allowing the swift attainment of Euro VI particulate mass and number standards.

In developed countries, the reduction of emissions from internal combustion engines will become ever more challenging, as more efficient methods of vehicle operation, such as future diesel electric hybrid systems and exhaust energy recovery, place further thermal constraints on the current state-of-the-art. The stop/start advantages of a hybrid and anti-idling systems reduce the time available for thermal particulate filter regeneration along with creating multiple low temperature starts during normal operation. Exhaust energy recovery systems will require high differential exhaust temperature in order to attain sufficient conversion efficiency placing further constraints on current thermal management approaches.

In order for the diesel electric hybrids to be cost effective for market introduction, the cost of the diesel engine must come down. Achieving US Tier 2 Bin 5 and Euro VI emissions standards with a simple low cost diesel engine will be a key requirement for meeting stricter vehicle efficiency standards.

Barro Christophe / ETHZ

Analysis of PM and PN in Dual Fuel Engine, Fuelled with Natural Gas and OME

Global warming due to CO_2 emissions as well as local NO_x and soot pollution are of major concern for current emission legislation limits. Natural gas with a high methane concentration emits less CO_2 compared to diesel and gasoline due its lower carbon to hydrogen ratio. Diesel pilot injection represents a flexible and reliable ignition source for a gas engine. However the soot emissions during the diesel combustion are not negligible. The use of oxygenated fuels instead of diesel can reduce the particulate matter emissions during the pilot fuel combustion. Although a lot of works have been done with oxygenated fuels in diesel combustion, further studies of oxygenated fuels in dual fuel engines are still required.
The aim of this work is to investigate the effect of OME_{2-4} (Poly**O**ximethyldi**M**ethyl**E**ther) as pilot fuel in dual fuel combustion. Therefore a set of measurements are carried out in a duel fuel engine. The investigations are compared with standard diesel as pilot fuel. The main focus lies on the analysis of the combustion behaviour and on the according pollutant emissions (NO_x and soot). More precisely the effects of OME_{2-4} on the gaseous fuel combustion are investigated as well as NO_x emissions and particulate mass, number and size distribution.
The exhaust gas measurements in the dual fuel engine attest that OME_{2-4} emits a negligible amount of soot particle compared to similar operation condition with diesel. The use of OME_{2-4} leads to a high soot reduction. Soot particles with OME_{2-4} are only detected in operating conditions with high EGR rate and high share of pilot fuel. The oxygen content of OME_{2-4} (around 46 wt. %) inhibits the formation of soot in the pilot fuel spray. Furthermore, OME_{2-4} reduces the minimum required amount of pilot fuel to ignite the gaseous mixture in the cylinder especially at low load conditions. The use of OME_{2-4} decreases the ignition delay and therefore increases the speed of the flame propagation through the gaseous mixture. This allows the injection of a smaller amount of pilot fuel with OME_{2-4} compared to diesel. As a result to run the engine with the same overall stoichiometric conditions, the amount of natural gas can be increased. The lower share of pilot fuel further reduces the tendency to form soot particles during the pilot fuel combustion.

Beck Harald / MAN Truck & Bus AG, Germany

Particle number measurement according to PMP protocol and direct measurement

Homologation procedure according to UN-ECE Regulation 49 demands particle counting from prediluted exhaust. In particular this means a sample is taken from the partial flow diluter upstream the gravimetric filter holder. The representative sample volume taken from the partial flow dilution tunnel is fed back downstream the filter holder. The removed volume has to be taken into account for calculation of the gravimetric filter load and respectively for the emitted particle emission. Interferences of the particle number counting procedure on the gravimetric particle mass analysis are therefore obvious. Meanwhile most of the instrument manufacturers offer particle counting systems with raw exhaust sampling options using high dilution modes. Therefore the following study aims at the comparison of particle number counting results according to PMP protocol and the particle counting in the direct exhaust. Measurements were performed with a EURO VI diesel engine with exhaust after treatment system and with a gaseous engine equipped with a three way catalyst. Sampling was performed using a NOVA Microtrol 6 partial flow dilution tunnel in combination with an AVL APC 489 advanced for particle counting. A second AVL APC 489 was connected to the direct exhaust near the sampling position of the Microtrol 6. Test cycles were according to EURO VI Worldwide Harmonized Transient Cycle and Worldwide Harmonized Stationary Cycles (WHTC and WHSC). In case of the diesel engine equipped with a diesel particle filter results show an overestimation of the direct measurement compared to the PMP setup of 10% (weighted results) for the WHTC and of 5 % for the WHSC. Using the gaseous engine overestimation of particle number values was also found in case of the direct measurements. Tendencies of overestimation are higher compared to the diesel engine (up to 50 %). In all cases results both with direct and PMP setups passed EURO limits. Sampling upstream the DPF both counting systems show very similar results only 2 orders of magnitude higher than downstream DPF. As conclusion the presented results show a promising opportunity to start an open discussion to introduce the direct particle counting method for homologation procedure for EURO VI engine certification.

Beránek Vit / Czech Technical University Prague

Effects of high-speed driving on particle number emissions of gasoline cars

The recent and ongoing increase in power-to-weight ratio of passenger cars, along with advances in electronic engine controls, have rendered the current European type-approval procedure obsolete, as the emissions limits do not apply to a considerable part of the engine operating envelope, namely, engine speeds and loads higher than those covered by the New European Driving Cycle. At higher loads, many European spark ignition cars use commanded fuel enrichment - a practice recently prohibited in the United States - to increase maximum engine power and to reduce exhaust gas temperatures. Enrichment can increase particulate matter emissions by orders of magnitude [Kayes, Environ. Sci. Technol., 1999, 33 (22), pp 3957–3967].

While only a fraction of the drivers regularly use full load during city driving, on vehicles with smaller displacement engines, full power is used even by conservative drivers during freeway driving: at 120 km/h, overcoming the air drag requires nine times more power, and three times the power is needed to achieve the same acceleration rate, compared to 40 km/h. With nominal freeway speed limit (in the Czech Republic and many other European countries) of 130 km/h, and 140-150 km/h not being an uncommon travel speed during commuter rush hour, “excess” particulate matter emissions caused by enrichment, and not subject to the emission limits, are of a concern.

In this study, five gasoline cars, two with port fuel injection (PFI, Euro 3 and 5), and three with direct injection (DISI, Euro 5 and 6), including one hybrid vehicle, have been subjected to multiple driving cycles driven on a chassis dynamometer, including the 150 km/h maximum speed version of the motorway part of the Artemis cycle. None of the cars had a particle filter. Particulate mass emissions were measured by gravimetric method, number concentrations of non-volatile particles were measured by a particle counter per EU type approval requirements, and on some vehicles, particle size distributions were measured by Engine Exhaust Particle Sizer.

The DISI engine used in a hybrid featured, among other, advanced variable valve timing, did not use enrichment, and exhibited very low particle emissions during all cycles, suggesting that maintaining low emissions is well within the capability of current gasoline engines.

The remaining four vehicles exhibited a considerable increase in both particle number and mass emissions during the Artemis motorway cycle compared to both NEDC and WLTP cycles, suggesting that “off-cycle” emissions of particulate matter from gasoline engines pose a problem to be addressed. The relatively high PFI engines particle emissions during enrichment suggest that the spark ignition engine particle emission problem is not limited to DISI engines but also to engines that due to cost saving measures do not use state of the art technical solutions.

High exhaust flow and temperature present a technical challenge during high-power tests on light-duty vehicles. In this study, a larger dilution tunnel for heavy-duty diesel engines was used for some vehicles. There, however, at low engine power levels, the long residence time of undiluted exhaust and high dilution ratio are among the concerns to be investigated.

Berhardt Alexander / IZES Germany

Electrostatic precipitation in small scaled biomass boilers:

With the intention of developing an electrostatic precipitator (ESP) for small-scaled biomass combustion systems, several laboratory and field tests were carried out to transfer the theoretical approaches into the practice. The main aim of the development is to be able to separate the fine dust out of the exhaust gas of biomass boilers with a maximum nominal heat output of 150 kW. By applying this secondary emission reduction measure, it should be possible to meet the new German legal limits for the fine dust emissions from biomass combustions. The IZES gGmbH in cooperation with the Hoval AG, has performed R&D since 2011 in the field of electrostatic precipitation and has currently started a small series field test with 16 prototype ESPs. The described system represents a novel approach for the development of an ESP for the usage in domestic applications: The precipitator can either be applied as a direct integration into the cold end section of the biomass boiler, or it can be applied as an adaptive solution, integrated into an especially developed precipitation box which is installed between the cold end section and the suction fan of the boiler. Both solutions imply that the ESP becomes an inseparably part of the boiler system, hence the described development differs from the in this size category widely used chimney-installation-type ESPs. With the combination of the boiler and the precipitation system, several benefits and symbioses effects can be used: Exemplarily, the communication between the boiler and the precipitator ensures a more detailed knowledge and a mutually harmonization of the actual state of operation of both systems. Even in case of using the directly integrated solution, some components of the electrostatic precipitator are already realized. The collecting electrode, the ash removal system and the exhaust gas drainage system are already provided by the boiler. Hence, the development of the main components of the precipitator, such as the high voltage control and supply unit, the insulators, the discharge electrode and the precipitation box, are presented and discussed. The presentation should give a brief overview over the ground laying theory and the approaches, which have been made during the development, before a detailed description of the laboratory and field test results is shown. Therefore a main focus of the presentation will be the evaluation and discussion of the single development steps, which started in the laboratory and were tested within the field tests. Concerning the laboratory development, investigations on the electromagnetic compatibility (EMC) or the electric performance of the discharge electrodes are the most characterizing results which are shown. Following exemplarily results from the 15 minute measurements for standard wooden and alternative non-wooden fuels from the field tests are presented. The presentation of gravimetrical measurements according to the DIN VDI 2066, finally evaluates the overall performance of the developed ESP. The description and discussion of the observed differences between theory and practice, especially between the laboratory and the field tests, conclude the presentation.

Besch Marc Cyrill / West Virginia University, USA

Characterization of Atmospheric Dispersing Exhaust Plume during On-Road Operation of Latest Technology Heavy-Duty Trucks

Traditionally, particulate matter emissions data used in emission inventories are collected during engine and chassis dynamometer testing, performed in controlled laboratory environments, whereby natural atmospheric interactions are replicated by means of a full- or partial-flow dilution tunnel that may generate/suppress physical mutations. Several physical processes that may impact particle size distribution and composition of an aerosol occur during exhaust atmospheric dilution. Furthermore, laboratory-based measurements use HEPA filtered dilution air, whereas background air during atmospheric dilution may contain a variety of biogenic aerosols and dust particles that could impact or alter the formation dynamics of nucleation mode particles in the exhaust plume. Studies in a large scale environmental wind-tunnel have identified turbulence intensity (TI) within the dispersing exhaust plume to be a primary driving factor for the formation of nucleation mode particles.

This study was employing a novel experimental methodology that allowed to integrate atmospheric and laboratory PM sampling techniques in a unique setup. In a first phase, particulate matter emissions were measured with WVU's transportable emissions measurement system through a traditional full-flow CVS system while the test vehicle was operated over the road. During the second phase the exhaust plume was allowed to freely disperse and mix with background air after exiting the exhaust stack. A moveable sampling probe setup was installed within the boundaries of the exhaust plume making it possible to extract a partial sample from different locations within the three-dimensional structure of the dispersing plume. The extracted sample was routed through a heated sampling tube to a manifold and subsequently split between different particle measurement instruments, including; i) TSI EEPS® for particle size distributions, ii) CPC for total particle number concentrations, iii) TSI EAD for a proportional measure of particle surface, iv) Dekati DMM and AVL MSS for particle mass information, as well as v) a aethalometer to quantify black carbon content. Additionally, samples were collected on carbon grids for subsequent analysis of the particle's morphology via scanning electron microscopy. Turbulence intensities at the sample extraction points were measured using an omnidirectional hotwire anemometer.

The test articles for both phases included three heavy-duty tractors typically employed for goods movement applications, including a DPF equipped, MY' 2007, a DPF-SCR equipped EPA-2010 emissions compliant, as well as a stoichiometric operating and TWC equipped natural gas engine. Exhaust plume sampling was conducted at three characteristic steady-state vehicle speeds (i.e. 20, 35, and 45mph) and during a transient operation over highway and suburban driving conditions. For the latter, the extraction probe was held at a fixed position, whereas for steady-state experiments the probe was moved through the plume allowing to characterize particle emissions as a function of dilution rate and ratio. Finally, data collected during this study while the vehicle was operated over the road was compared to experiments conducted in an earlier study using an environmental wind-tunnel setup.

Bisig Christoph /University of Fribourg, Switzerland

Hazard assessment of Gasoline direct injection engine exhaust directly exposed onto the surface of a 3D human lung model

Background: Gasoline direct injection (GDI) engines are increasingly used, due to their greater power, better fuel efficiency, and lower CO_2-emissions, though with the drawback of emitting more (nano)particles than the older multiport fuel injection (MPI) [1]. The demand of implementing gasoline particle filters (GPF) on GDI vehicles is therefore growing. Studies on possible toxicity from gasoline exhaust are scarce, and most research so far has been performed with MPI engines (e.g. [2]). We therefore investigated the effects of whole diluted exhaust from a new GDI vehicle exposed to a sophisticated 3D human lung tissue model. In addition, changes of exhaust composition upon installation of two different GPF's and their effects on lung cell responses were compared.
Method: A GDI passenger car was driven on a chassis dynamometer in repeated Worldwide Harmonized Light Vehicles Test Cycles (WLTC) with no filter, or with either an uncoated GPF or coated GPF. The exhaust was diluted 1:10 and directly applied for 6h to a 3D human lung epithelial tissue model, with a 6h post-exposure time period in an incubator. The lung model was composed of a tight layer of bronchial cells (16HBE14o- cell line), supplemented with human monocyte derived dendritic cells at the bottom and monocyte derived macrophages on top, cultured at the air-liquid interface as described [3]. Biological endpoints included cytotoxicity, pro-inflammation, oxidative stress, and mutagenicity. In parallel to the exhaust exposure, filtered air was directed over identical cells as a control. Additionally, the results were then compared to diesel exhaust, which was obtained (WLTC cycle for 6h) and analyzed in the same manner as the GDI exhaust.
Results: Both GPF's significantly reduced the particle number in the exhaust and did not change concentrations of CO, NOx, and THC, the latter two were generally very low. Unfiltered exhaust did not induce any of the biological markers significantly (e.g. pro-inflammation, oxidative stress, and mutagenicity), but small differences were observed, e.g. on the gene expression analysis, an increase in 5/10 assessed genes was observed in unfiltered exhaust compared to filtered exhaust, but none of them significantly. Filtered (both coated and uncoated GPF) exhaust did not induce any of the tested biological markers. On the other hand, diesel exhaust showed a significant increase in oxidative stress and pro-inflammation response, confirming the responsiveness of the system we are using.
Conclusion: In contrary to diesel exhaust, the exposures of GDI exhaust did not induce adverse effects in an acute exposure scenario. Though minor effects of unfiltered GDI exhaust are observed when compared to both GPF exhausts, where both GPFs diminished all adverse effects. More experiments with longer exposures in the future are, however, recommended.

Acknowledgment: This work was supported by the Adolphe Merkle Foundation, the Swiss Federal Office for Environment, the Swiss Federal Office of Energy, Schweizer Erdölvereinigung, and VERT Association.

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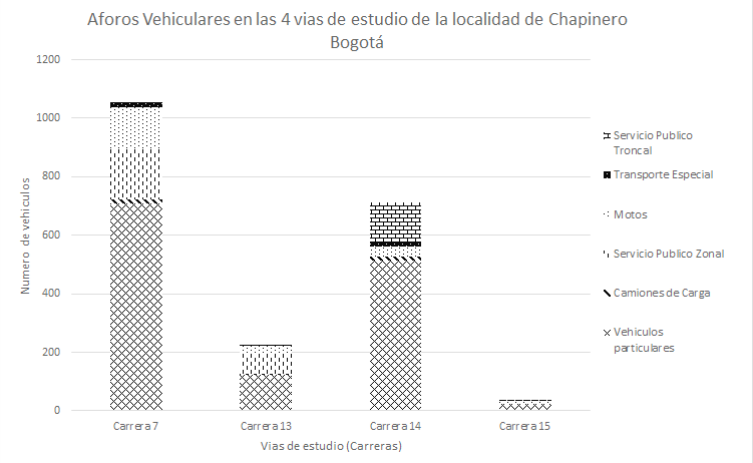
Bonilla Lorena Catalina / District Secretariat of environment – Bogotá

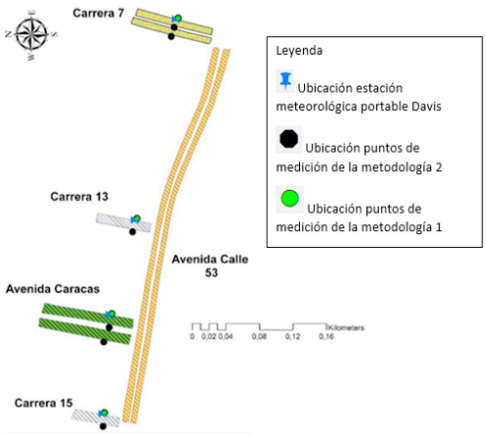
Study of Personal exposure to nanoparticles considering meteorological variables in 4 roads with different types of vehicles in Bogotá

The Secretaría Distrital de Ambiente (District Secretariat of Environment) of Bogota-Colombia, considering that the Nano-particles have impacts on public health, and knowing the significance of this pollutant on air pollution, has developed in cooperation with the academy a study of Personal exposure to nanoparticles considering meteorological variables in 4 roads with different types of vehicles in Bogotá.

In the frame of the Plan Decenal de Descontaminación del Aire para Bogotá -PDDAB (Decennial Plan of Air Decontamination for Bogotá) adopted in the city since 2011 and be aimed to reduce the air pollutants from the emission sources, in addition with the Program of Implementation of diesel particulate filters - DPF for Bogota, in association with the National University of Colombia and started since 2013, this work also supports the construction of the base-line of Nano-particles concentration in urban microenvironments and helps also in the control and regulation of the diesel particulate filters project.

The study has been developed in 4 parallel roads of the city, on each road, the personal exposure to Nano-particles has been measured with a diffusion size classifier equipment DISC-mini. Also meteorological variables as: temperature, humidity, wind speed and direction were measured with a Davis meteorological Station located at 2.5 m high. The selected day time was the morning rush hour, due to the high concentrations of PM2.5 and Black Carbon reported on the air quality monitoring stations of the city. Two methodologies were used: one considering only one side of the pathway and another considering both sides of the road, a difference between those two procedures was found (Figure 1). Each road was characterized with vehicular traffic counts and therefore was possible to compare the variation on personal exposure according to the average number of vehicles passing on the road per hour (Table 1). The results show higher concentrations and variation on the data in roads with an important number of Diesel vehicles of different types of vehicles; also it shows a high level of peak concentration for nanoparticles above 1'000.000, near to 15% in all principal roads, for the tertiary road (Kra 15) is 0%.
The relation of the number of the concentration with the meteorological variables, was considered, as well. The correlation between the variables was very low for the results. Therefore it was found that the concentrations are highly dependent on the proximity to the source and is necessary to establish correlations with other parameters such as PM2.5 and Black Carbon.





Vías	Carrera 7	Carrera 13	Carrera 14	Carrera 15
Calzada Mixta oriental	1046 cm	950 cm	625 cm	731 cm
Calzada mixta Occidental	1058 cm	-	630 cm	-
Calzada TM Oriental	-	-	725 cm	-
Calzada TM Occidental	-	-	725 cm	-
Anden Oriental	260 cm	521 cm	917 cm	248 cm
Anden Occidental	592 cm	680 cm	850 cm	233 cm
Separador Central	98 cm	-	475 cm	-
Ciclo vía	-	195 cm	-	-
Distancia Cll. 53 – punto de medición	7461 cm	3100 cm	4852 cm	2882 cm
Ancho total de la vía	3054 cm	2346 cm	4947 cm	1212 cm

Characterization of roads

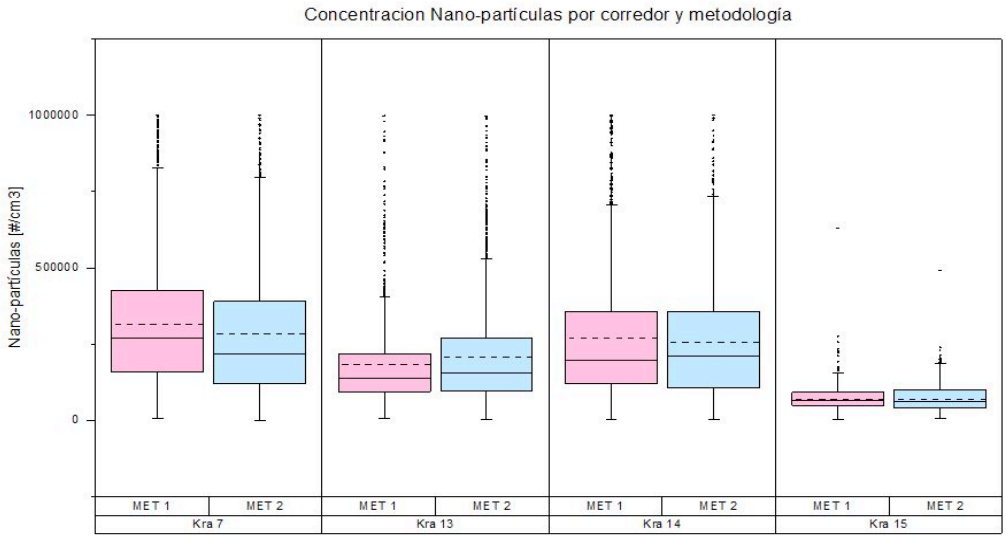
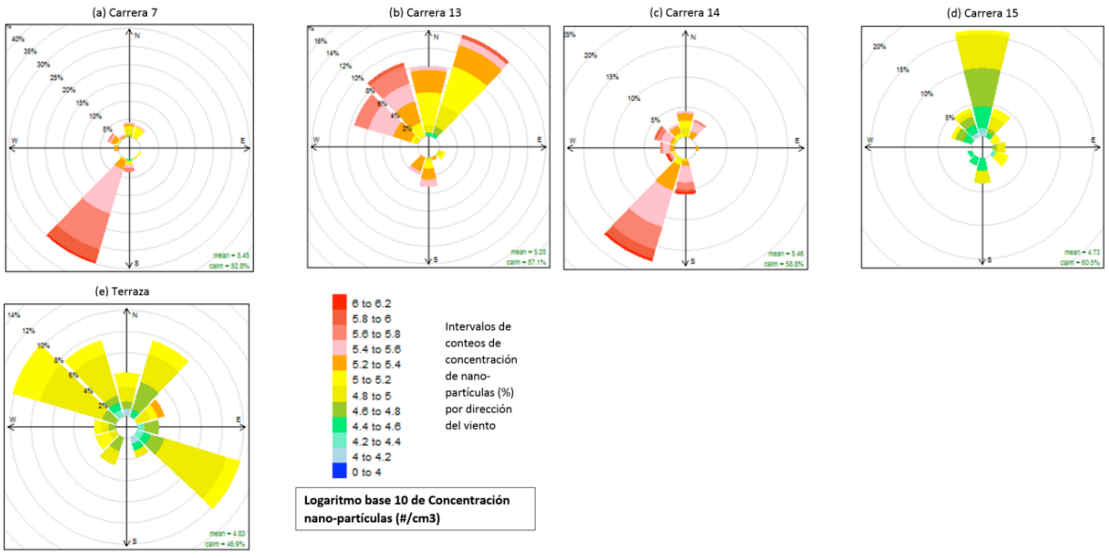


Figure 1 Nano-particles concentration for each road and Methodology



Borovinskaya Olga / TOFWERK AG Switzerland

Online determination of element composition and mass of single airborne particles by ICP-MS

Real-time monitoring of airborne particulate matter (APM) is used in many applications for studying the kinetic behavior of aerosols and identification of emission sources. Various analytical techniques, such as AMS, LIBS, PALMS, have been developed, and successfully applied for the real-time chemical analysis. However, for the detection of heavy metals the aerosols are commonly collected on a filter for a sufficiently long time, digested and measured in bulk by using inductively coupled plasma optical emission (ICP-OES) or mass spectrometry (ICP-MS), later being more sensitive. This collection approach suffers from low time resolution and introduced contaminations.
Real-time multielement monitoring of APM in ambient air by ICP-MS became possible with the development of interfaces, such as differential mobility analyzer or gas exchange device (GED), which enable exchange of ambient air to argon, required for stable operation of the ICP source.[1] Several methods were proposed for the quantification of aerosol composition, for example, by using a standard metal gas generator to calibrate the instrument response.[2] If the number concertation of particles in the air is low ($<10^8$/ml), single particle detection becomes necessary. With currently available commercial ICP mass spectrometers only one or maximum two elements in individual particles can be monitored, limiting the application of online sampling.
In this study we coupled a recently developed gas exchange device (GED) with a new ICP-time-of-flight (TOF)MS (icpTOF) and demonstrated the capabilities of the this setup for real-time monitoring of APM and aerosol detection down to the single particle level. GED provides complete particle sampling without losses and memory effects and sustain stable plasma conditions. The icpTOF provides simultaneous detection of the entire mass range of elements and µs-time resolution.[3] These features and high sensitivity render the multielement detection of single aerosol particles possible. We present two new calibration approaches for the quantification of elemental composition and element mass of single airborne particles. Both approaches were validated by measuring the reference urban particulate matter from NIST suspended in Ar. The feasibility of the technique was demonstrated for outdoor and indoor air samples, car exhaust, and smoke samples.

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Burton Kerrie / University of Wollongong

Are respiratory protection standards protecting worker health against ultrafine diesel particulate matter emissions? An Australian Perspective

Aim: Ultrafine diesel engine emissions are known to cause adverse health impacts including lung cancer, cardiovascular and irritant effects (World Health Organisation 2012). Respiratory protective devices are commonly used to mitigate worker exposure to many hazardous contaminants, especially in heavy industry such as mining and refining. Current standards to evaluate penetration through respirator filter media may not consider ultrafine particles due to the diameter of the challenge aerosol and the detection limit of the instrument (Eninger et al. 2008). Nor do they test penetration at flow rates representative of moderate to heavy work rates. Research is currently being undertaken at the University of Wollongong, Australia, to develop a method to measure penetration through respirator filter media using diesel emissions, rather than the standard challenge aerosol of NaCl, at flow rates consistent with moderate to heavy work rates.
Methods: Emissions from a Detroit D706 LTE diesel engine were fed into an experimental chamber which was purpose built for the study. Penetration through a range of commonly used respirator filters in Australian workplaces was determined by particle count at diameters ranging from 5.6 – 560nm, using an Engine Emissions Particle Sizer (EEPS). Penetration was also measured by mass of Elemental Carbon, using NIOSH 5040. Flow rates were as designated in AS/NZS 1716 (Standards Australia International Ltd & Standards New Zealand 2012) and ISO DIS 16975 – 1.2 Work Rates 2 and 3 (ISO 2015), consistent with moderate to heavy work rates.
Results and Conclusions:
A method has been developed and validated and a pilot study completed. Initial findings indicate penetration exceeded standards specified limits for filtering efficiency for a number of filters for the size range <50 nm, when measured as a function of particle count. Penetration through the filters was found to increase as flow rate increases. These results differed from the penetration by mass of elemental carbon through the respirator filters, using a paired samples t-test at a significance level of 0.05. This research is relevant as it has been postulated that ultrafine particles may contribute to adverse cardiovascular mortality and morbidity associated with diesel engine emissions (Martinelli, Olivieri & Girelli 2013) hence it is important to determine if these smaller size particles are penetrating through respirator filter media and may be inhaled by workers.

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Cachón Luis / TESTO Germay

Next Generation of Particle Number Instruments for Vehicle Type Approval and Quality Control of DPF Kerbside

Introduction:

The latest news regarding Real Driving Emissions RDE are likely to have a great impact on policy maker decisions, development in the automotive industry and testing procedure for research and control organizations in general.
This poster presents through several application examples the next generation of particle number instruments for vehicle type approval and quality control of DPF Kerbside:

- NanoMet3: Portable Emission Measurement System for Particle Number PEMS-PN
- PEPA: Portable Emission Particle Analyzer, ultra-compact instrument for the periodic technical inspection of particle number.

This portable nanoparticle instrumentation based on diffusion charging enables a new measuring procedure in automotive application to measure number concentration and diameter of nanometer sized particles in the size range 10 – 500 nm. Diffusion charging technology has been already satisfactory proved for personal exposure monitors. 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:

Joint Research Centre – JRC on behalf of the European Commission has completed the evaluation of the PEMS-PN measurement technology for oncoming Real Driving Emissions within EURO 6c legislation in LDV. After an extensive measurement campaign with five test vehicles and over 280 driven sub-cycle tests, NanoMet3 was rated among all 5 candidates as the best measurement instrument in terms of accuracy and on-board capability. Moreover, NanoMet3 has been honored as Golden Instrument for the Inter Laboratory Correlation Exercise – ILCE to be finished until March 2016.

The European Commission started in January 2016 a pilot project for HDV to investigate PEMS-PN technology for In-Service conformity. NanoMet3 has been selected as candidate for In-Service Conformity procedure and first results should be presented.

The Swiss ordinance regarding periodic control of the construction machinery on the field will contribute to discuss a similar way of testing the off-road vehicles for the In-Service Monitoring under the European NRMM Stage V legislation.

Recent measuring campaigns in different cities have demonstrated the necessity of a periodic technical inspection of DPF with portable instrumentation. The results should open the discussion for a new periodic inspection procedure.

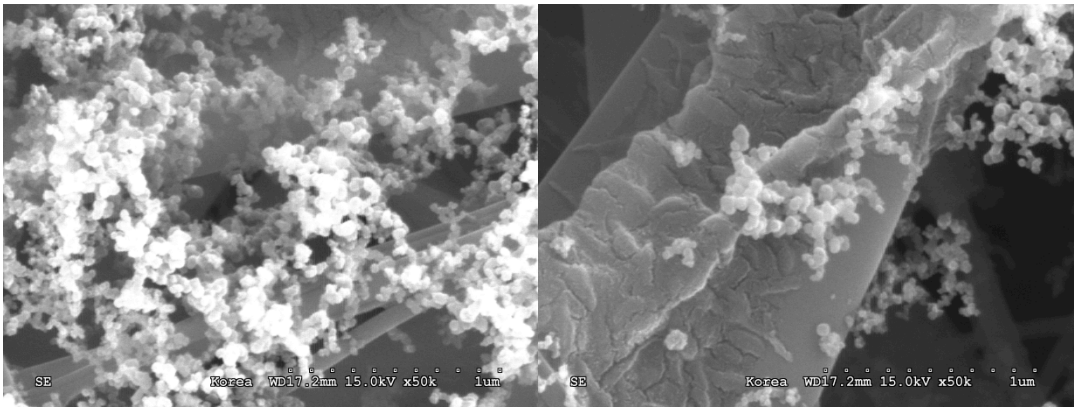
Cho Jaeho / Korea University

Size-resolved Nano-particle Filtration Characteristics with Metal foam Gasoline Particulate Filter (GPF) for a modern GDI vehicle

Developing trends of a gasoline direct injection (GDI) engine enhanced high fuel efficiency and low CO_2 emissions compared with the conventional port fuel injection (PFI) engines. Gaseous emissions from GDI vehicles, with the exception of particle number (PN) emissions, have been significantly reduced using advanced three-way catalysts (TWCs) and stoichiometric operations. Mixture preparation schemes and combustion mechanisms of the GDI engine emitted significantly higher amounts of PN than the traditional PFI engines or diesel engines that have been equipped with particulate filters, especially during the cold-start phase and at high acceleration points. Moreover, advanced GDI engines produced considerable amount of nucleation mode particles of semi-volatile and solid particles. Substantial amounts of sub-23 nm particles was reduced by TWC-GDI vehicles, however, additional after-treatment system should be applied for filtering accumulation mode particle.

The purpose of this this study is for the comparison of nano-particle emission behaviors between TWC and metal foam type gasoline particulate filter (GPF, Alantum Co.) system equipped in a modern GDI vehicle. The adoption of GPF in GDI vehicles is straightforward measure for reducing particle emissions. New design concepts of metal foam type filter materials with thin wall and low porosity provided moderate pressure built-up through GFP substrates, because soot accumulation quantity by the GPF-GDI engines showed significantly lower than the diesel particulate filter (DPF) equipped diesel engines. Size-resolved nano-particle characteristics at engine-out, down-stream TWC, and after GPF positions were determined with differential mobility spectrometer (DMS500, Cambustion Co.). Exhaust gas temperatures (°C) and pressure drop (kPa) were simultaneously measured. Compared to TWC-GDI case, size-resolved particle concentration from the TWC-GPF-GDI engine presented that both the nucleation and the accumulation mode particles were simultaneously reduced under steady-state part-load engine operating conditions.

To provide the time-resolved PN filtering efficiency of the GDI vehicle, TWC only (base after-treatment system) and TWC-GPF system were compared over the new European driving cycle (NEDC). By using the DMS500, the real-time PN concentration and size distribution with TWC-GPF configuration were compared with TWC only case to evaluate the fraction of sub-23 nm nucleation mode and accumulation mode particles. The metal foam GPF provided excellent performance for the reduction of sub-23 nm particles (93% of the filtration efficiency) and reasonable performance for particles over 23 nm (63% efficiency). The total PN emissions of the base GDI (TWC) and the TWC-GPF-GDI vehicles for the NEDC were1.17E+12 and 4.99E+11 N/km with condensation particle counter (CPC 3010D, TSI), respectively, and the reduction rate of the GPF reached 57% without penalties in the other regulated emissions, back-pressures, and fuel economies.



(a) TWC only (b) TWC-GPF

Figure. FESEM images of particulates filtrated on fluorocarbon-coated glass filter in NEDC

Project Funding: This study was supported by the BK21 plus program (21A20131712520) through the National Research Foundation (NRF) funded by the Ministry of Education of Korea. We are also grateful to the Alantum Company for their technical assistance on the development of the metal foam GPF for GDI engine.

Czerwinski Jan / AFHB Biel Biel, Switzerland

Particle Number Reduction of GDI-Cars with GPF's

The nanoparticles (NP) count concentrations are limited in EU for Diesel passenger cars since 2013 and for gasoline cars with direct injection (GDI) since 2014. The limit for GDI was temporary extended to 6 x 10^{12} #/km (regulation No. 459/2012/EU).
Nuclei of metals as well as organics are suspected to significantly contribute especially to the ultrafine particle size fractions, and thus to the particle number concentration.
The invisible nanoparticles (NP) from combustion processes penetrate easily into the human body through the respiratory and olfactory pathways and carry numerous harmful health effects potentials.
In the project GasOMeP (Gasoline Organic & Metal Particulates) metal-nanoparticles (including sub 20nm) from gasoline cars are investigated for different engine technologies.
In the present paper some results of investigations of nanoparticles from five Di gasoline cars are represented. The measurements were performed at vehicle tailpipe and in CVS-tunnel. Moreover, five variants of "vehicle – GPF" were investigated.
The PN-emission level of the investigated GDI cars in WLTC without GPF is in the same range of magnitude very near to the actual limit value of 6.0 x 10^{12} #/km. With the GPF's with better filtration quality, it is possible to lower the emissions below the future limit value of 6.0 x 10^{11} #/km.
There is no visible nuclei mode and the ultrafine particle concentrations below 10mm are insignificant.
Some of the vehicles show at constant speed operation a periodical fluctuation of the NP-emissions, as an effect of the electronic control.

Czerwinski Jan / AFHB Biel Biel, Switzerland

Experiences of Testing NO_2 for Diesel and NH_3 for Gasoline Cars

Public concern and complaints regarding ambient air in zones of dense traffic pertains to two compounds of nitrogen, nitrogen dioxide (NO_2) and ammonia (NH_3); both are toxic and strongly irritant, such that legal limitations are under discussion. This paper contributes to measuring methods as already in part proposed by GRPE subgroup WLTP-DTP (Worldwide Light Duty Test Procedures – Diesel Test Procedures) for NO_2.
Despite legally lowered NO_x emission levels, lumping both, NO_2 and NO, levels of NO_2 have risen in cities and agglomerations as a result of both, deployed catalytic exhaust after-treatment devices and low sulphur Diesel fuels. In present tests two different combinations of NO_2 measuring methods as proposed by WLTP were checked on Diesel cars for practicability in handling and accuracy. These integral, indirect methods ($NO_2 = NO_x - NO$) have been found as useful tools for estimate of NO_2 and with use of appropriate analyzers a satisfactory accuracy was attained.
Furthermore, attention was brought to ammonia (NH_3) emitted by gasoline engines with three way catalysts (TWC) which ought not to be ignored while on the other hand SCR systems for Diesel engines are strictly regulated. Emission levels of more recent TWC turned out to be mostly below 20 ppm NH_3. Vehicle of older technology exhibited significantly higher levels, about 10 times more.
As chemical reactions depend on pressure and temperature (= i.e. flow condition in CVS-tunnel) as well as concentrations, doubts need to be considered on accuracy of results based on chemical reactive substances. Nevertheless, clear tendencies regarding changes of concentrations of NO_2 and NH_3 along the path-way could not be observed.

Czerwinski Jan / AFHB Biel Biel, Switzerland

Quick-check of DOC and SCR for Inspection of Emission Control Devices

Due to possible malfunctions of the exhaust aftertreatment systems the stability of Diesel engines emissions should be periodically controlled. VERT has developed inspection methods for retrofit emission-control devices, which have been proven so efficient, reliable and cost effective that they are to be recommended herewith for all engines and applications.

DOC, Conversion Efficiency: A DOC may be part either of a DPF-system or of an SCR-system or even standing alone. It may be inhibited by thermal or chemical poisoning or contamination. DOC-conversion efficiency depends primarily on temperature: In oxygen rich Diesel exhaust, conversion of CO to CO_2 starts at about 170°C and it reaches its full conversion level at about 210°C (light-off). By means of a load step at constant rpm, conversion capability of a DOC is determined very accurately and in very short time: Heating the exhaust gas up to 250°C on a simple roller-dyno and measuring the CO concentration curve during cooling down at the tail pipe – or inverse. This procedure reveals the exact status of the DOC within a few minutes.

SCR, Functionality of Selective Catalytic NO_x-Reduction: Functionality requires both, proper catalytic conversion of the SCR-catalyst system and the accurate injection of the urea-water solution “Adblue” to be done at the minimum permissible temperature. Again a simple load step enables to check all functions in one single run. Either heating the exhaust gas from idling temperature 150°C to 250°C, or following the cooling curve from 250°C to idle with a NO_x sensor at the tail pipe reveals, whether urea is injected, whether the right amount is injected, whether it is injected at the right temperature and whether the catalyst conversion is on the expected level. After this simple test, at any engine speed selected all required information is available. An even more precise control test is possible by an additional NO_x-measurement (sensor) upstream of the SCR.

Czerwinski Jan / AFHB Biel Biel, Switzerland

PN-PEMS: Testing Emissions of Diesel Passenger Cars in Laboratory and On-Road

PEMS – portable emissions measuring systems were introduced in the last stage of exhaust gas legislation for HD-vehicles in order to measure and to limit the real driving emissions (RDE). PEMS were also confirmed by EU to be applied for the LD-vehicles in the next legal steps.
PN-PEMS include the particle number (PN) testing in the on-road real world application.

In the present poster some results and experiences of measurements of two Diesel cars with PN-PEMS on the chassis dynamometer and on-road are presented.

The PN-PEMS consisting of AVL M.O.V.E and Matter-Testo-NanoMet3 was installed on each vehicle and the tests on the chassis dynamometer in the standard test cycles: NEDC, WLTC and CADC and on-road were performed.

As reference, the results of the stationary laboratory equipment (CVS and Horiba MEXA 7200) were considered.
For the real-world testing a road circuit was fixed: approximately 1h driving time with urban/rural and highway sections.

Repeated test on the same road circuit produce dispersing emission results depending on the traffic situation, dynamics of driving and ambient conditions. Also the calculated portions of urban, rural and highway modes are varying according to the traffic conditions.

PN-PEMS showed an excellent correlations with CPC in the tests on chassis dynamometer and it indicated very well the efficiency of DPF in eliminating the nanoparticles in real world driving

D'Anna Andrea / Università degli Studi di Napoli Federico II

Nanoparticle formation burning biofuels

Biofuels are gaining increased attention as alternative to fossil fuels. The main motivation is the mitigation of climate change and energy security objectives. Biofuels may produce less net carbon dioxide emissions than oil-based conventional fuels. Moreover, there is also a general idea about their ability to reduce exhaust emissions, particularly polycyclic aromatic hydrocarbons (PAHs) and particulate matter. In spite of this general belief, experimental results performed in laboratory-scale experiments and in engines have shown that the effect of biofuels on the formation of particulate matter is controversial. Biofuels produce pollutants similar to conventional hydrocarbon fuels and their formation can be promoted or reduced with respect to hydrocarbon molecules having the same number of C-atoms according to operative conditions.
The role of ethanol, dimethyl ether, and furanic fuels, namely furan, methylfuran and 2,5 dimethylfuran, as substituent to ethylene, on the formation of particulate matter is investigated in different flame configurations by using in situ optical techniques and differential mobility particle sizer.
Laser induced fluorescence and incandescence signals, correlated to small precursor nanoparticles and large soot particles, respectively, have been measured in premixed and counterflow diffusion flames of ethylene doped with different amounts of biofules.
In premixed flames, the addition of biofuels to ethylene reduces nanoparticle and soot particle formation. The effect is stronger for the soot particles, that is, particles with sizes larger than 10 nm, and in flames operated close to the soot threshold limit. The addition of biofuels even reduces soot particle concentration below the detection limit, whereas nanoparticles are still formed in large amounts. These results are confirmed by the measurements of the particle size distributions that show a dominance of sub-10nm particles in flames operated with increasing concentrations of biofuels.
The counter-flow diffusion flame configuration shows a different behavior. In the fuel side of the flame, typical of fuel-rich conditions in engines, a noticeable increase of both nanoparticle and soot particle concentrations is detected by adding biofuels. Conversely, in the oxidizer side of the flame, particulate matter is always reduced when biofuels are added to the fuel. The results show that the role of biofuels in the formation of nanoparticles and soot is not always in the sense of reduction, but it strongly depends on the combustion conditions. Moreover, if particulate matter concentration is reduced, the particle size distribution of the emitted particulate matter is dominated by sub-10nm particles.

Durantie Estelle / University of Fribourg, BioNanomaterials group, Switzerland

Comparing the bio-kinetic behavior of single ultrafine particles to agglomerates at the human respiratory epithelial tissue barrier *in vitro*

Adverse effects of particulate matter (PM) such as lung and cardiovascular diseases have become a worldwide priority concern as human are continuously exposed. PM is a complex mixture and numerous studies to get a better understanding on their hazardous properties have been reported.[1,2] Ultrafine particle (UFP) fraction (<100nm) of ambient PM, has aroused a particular interest since recent studies indicate a specific toxicological effect, and reduced lung function following inhalation of/exposure to UFPs.[3,4]
In order to better establish the risk associated to UFP inhalation, a clear understanding on their bio-kinetics at the air-blood barrier must be gained. Furthermore, UFPs tend to agglomerate and form structures up to several 100 µm in diameter. To date, however, the correlation of primary and secondary particle size, i.e. single particles vs agglomerates, and their cellular uptake and/or translocation across the air-blood tissue barriers are not yet understood.

The aim of the proposed work was to use a model nanoparticle, i.e. gold, since we have already established a protocol for the synthesis of single gold nanoparticles and defined agglomerates.[5] In order to study how agglomeration might affect the bio-kinetics, i.e. cellular uptake and translocation, of the particles at the lung-blood barrier interface we have used an advanced 3D lung model composed of human lung alveolar cells (A549), macrophages and dendritic cells (human monocytes derived) which was cultured at the air-liquid interface.[6,7] To simulate a realistic inhalation, the nanoparticles were deposited using an air-liquid interface exposure system enabling a dose-controlled deposition. Hence, specific concentration of single and agglomerate nanoparticles, with a hydrodynamic diameter of 50 and 190 nm, respectively, were nebulized onto the cells and after 24 hours post-exposure time, biological kinetic and biological response were analyzed. Cytotoxicity was determined by lactate dehydrogenase assay and pro-inflammation response by measuring the level of tumor necrosis factor α. Cell layer integrity was characterized by confocal laser scanning microscopy and permeability assay using FITC-dextran 4 kDa. Finally, the bio-kinetics of gold nanoparticles was assessed by determining the amount of gold in each compartment (apical, intracellular and basal) using the ICP-OES measurement technique.

No apparent cytotoxicity, cell layer damage or pro-inflammation was observed after exposure to single nanoparticles or agglomerates. The biological kinetics revealed that the majority of the nanoparticles, singles or agglomerates, were taken up by cells, and only a minor fraction, less than 3-10 %, was found in the basolateral side, which is similar to the translocation rate found in vivo for single gold nanoparticles.[8]

In conclusion, we have shown that single or agglomerate nanoparticles were found mainly intracellularly and only a low fraction has translocated. A longer exposure time to assess the nanoparticles fate, and exposure to bigger agglomerates should be assessed to see how agglomeration of singles particles can influence the cell up-take and the translocation of nanoparticles across the air-blood tissue barrier. It will broaden our understanding on nanoparticle-cell interactions and help in further understanding the biological impact of agglomeration of UFPs in comparison to single particles after deposition on the lung cell surface.

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Durdina Lukas / EMPA Switzerland

Implications of the new PM emission standard for aircraft engines

Aviation has been steadily growing since the early jet age. Consequently, so have its effects on the environment because air travel growth outpaces measures taken to reduce emissions. Although CO_2 and NO_x emissions contribute most to aviation's environmental impact, aircraft PM emissions pollute the air near airports and warm up the atmosphere. Their estimated impact on both a local and global scale is fraught with large uncertainties. One of the main challenges is the lack of reliable and representative PM emissions data. The current method for estimating aircraft PM emissions from airport operations is based on an approximation of the non-volatile PM (nvPM) mass concentration from smoke number (SN), a qualitative criterion of smoke visibility. Such data estimates have become increasingly unreliable for modern engines that produce no visible smoke. Moreover, there are no standardized data on PM number concentration, a metric more relevant for health effects. However, such data will become available as a result of the future standard for nvPM number and mass-based emissions from aircraft turbine engines. Here we utilize nvPM emissions and SN data determined from measurements at certification-like conditions from a widely used turbofan engine to assess the emissions from a standardized landing and takeoff (LTO) cycle as well as from approximated cruise altitude conditions with respect to SN-based methods and combustion models.

Engine exhaust was sampled and analyzed according to the current requirements for emissions certification. Engine tests were performed in an engine test cell of SR Technics at Zürich airport, Switzerland using a conventional Jet A-1 fuel. To obtain a representative sample, the engine exhaust was sampled at the engine exit plane by a multi-orifice probe. The nvPM concentrations were normalized as emission indices (EI, amount of pollutant per kg fuel burned). The measured nvPM emissions are affected by various factors, such as particle losses in the sampling system and fuel composition. Both these issues were addressed and corrected for.

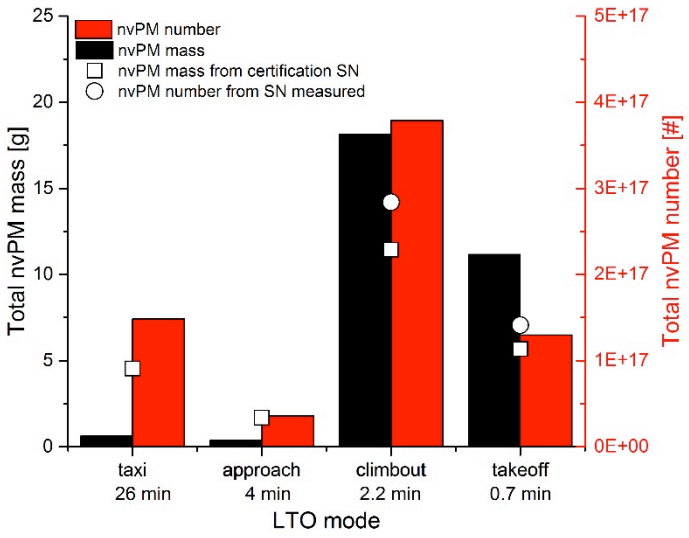

Figure 1. Example of the standardized LTO emissions from one aircraft.

Figure 1 shows the total emitted nvPM mass and number per aircraft (two engines) in the four modes of the LTO cycle defined by the sea level static thrust (7% taxi, 30% approach, 85% climb out, 100% takeoff) and for the corresponding durations. We can see discrepancies between the SN-derived and measured nvPM mass. At low thrust, the SN-based data grossly overestimated the emissions, whereas they underestimated the emissions at the two highest thrust levels. It is also evident that aircraft engines emit a significant number of particles. Idling aircraft, although emitting low total nvPM mass, are major sources of nanoparticles within the airport, whereas the climb out produced the overall highest emissions of both nvPM number and mass. The future nvPM mass and number emissions data will allow to create more accurate PM emission inventories for airports, up to now based only on PM10 and PM2.5 converted from SN, and dispersion models.

Fleischmann Rafael / Technion Haifa, Israel

Buses retrofitting with diesel particulate filters: effects on nanoparticle emissions and vehicle performance

Israel's public transportation system is strongly based on diesel fueled buses, which are known to represent a major source of particulate matter emissions in urban centers with subsequent adverse health effects [1]–[3]. Due to the long service life of these vehicles, a large number of buses with older emission control technologies are in use. Approximately a half of Israeli buses fleet is composed by Euro III or older technology vehicles. Retrofitting in-use buses with best available aftertreatment technologies appears to be a cost-effective measure to address the problem of elevated pollutant emissions from older vehicles.
The objective of this study is to evaluate the reduction in nanoparticle emissions of in-use diesel buses retrofitted with Diesel Particulate Filters (DPF) and to assess influence of retrofitting on the buses performance in real-world usage conditions. DPF influence on particle number (PN) concentrations and size distribution, as well as on back-pressure, fuel consumption, maintenance and drivability aspects were investigated during an 11-month period of operating in real-world usage conditions.
18 Euro III buses of popular makes were selected for the experiment: 9 urban buses and 9 intercity coaches. They were retrofitted with CRT-type DPFs from three different manufacturers. A reference group composed of 18 same buses without an aftertreatment system was used to isolate the impact of DPF on buses performance.
The vehicles were equally divided into three regions of different topography: flat, hilly and mixed.
PN concentrations and size distributions in the bus exhaust gases were measured both upstream and downstream the DPF. Each vehicle was tested under four different operating regimes: low idle, high idle, free acceleration and 85% of rated speed at engine's full load. TSI 379020A-30 was used for sample conditioning and TSI EEPS 3090 for PN concentration and size distribution measurements.
PN measurements were performed three times: shortly after DPFs installation, and about 4 and 9 months later.
Even though DPF-equipped buses present a net increase of about 2% in fuel consumption, measurement results indicate PN reduction of more than 97%. No relevant discrepancy was found among the different DPF makes. Backpressure values were found to be under acceptable level of 150 mbar. An example of the measured engine-out and tailpipe PN size distributions is shown in Figure 1.

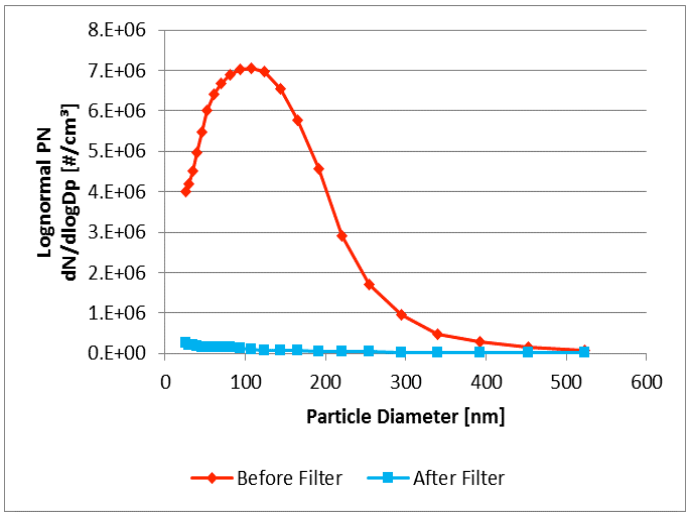

Figure 1: Example of PN emissions size distribution (bus in the Haifa area under low Idle)

The authors appreciate the financial support of the Egged bus company and the fruitful collaboration with the Israel Ministry of Environmental Protection and VERT Association.

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Foppiano Debora / PSI Villigen Switzerland

Behaviour of ZnO nanoparticles during high temperature treatment: on-line, size resolved elemental analysis

ZnO is one of the most relevant metallic ENPs regarding possible high exposures and it is often used for paints, impregnation and waterproofing sprays.
In this work we aimed to study the behaviour of ZnO nanoparticles during high temperature treatment and to understand the influence of the different atmospheres on the redox-sensitive Zn (Ludwig, 2001). This has to be considered as a preliminary study in the frame of a more complex scenario, such as the release of ENPs from waste incineration processes.
For a complete characterization of the gas-borne nanoparticles emitted after high temperature treatment was needed to determine on-line both the size distribution and the elemental composition.
The experimental setup consisted on a tubular furnace, used as lab-scale incinerator, connected to a modified Scanning Mobility Particle Sizer (SMPS) and an Inductively Coupled Plasma Mass Spectrometry (ICPMS). This coupling was achieved with a modified SMPS operating with argon instead of air and was recently developed and validated (Hess, 2015 a, b), in order to determine on-line the particle size distribution and elemental composition in aerosols and process gases.
Among different technique the SMPS is one the most suitable to determine online particle size distribution and concentration of gas-borne particles. On the other hand, multi elemental techniques as Inductively Coupled Plasma Mass Spectrometry (ICPMS) (Krystek, 2011), are often used to determine off-line the chemical composition. However contamination or morphology alteration of the particles for offline analytical methods must not be neglected.
In this study ZnO is introduced in the furnace both as powder and as dried particles in a gas stream starting from a suspension with a polymeric additive (Polyacrylic acid, 0.1% wt) as dispersant. Before reaching the SMPS-ICPMS, the generated aerosol is passed through a rotating disk diluter (RDD) and a heating tube, that allow an adjustable and high dilution ratio and a well-defined flow of the aerosol.
Scanning Electron microscopy and X-ray diffraction (XRD) were also used to study the effect of the thermal treatment on the morphology and the chemical pattern.

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Fraboulet Isaline / INERIS France

Validation and comparison of methods of measurement of the condensable fraction of aerosols emitted by residential wood combustion appliances and boilers

The 20/20/20 target for Europe, i.e. to decrease the emissions of greenhouse gases by 20 % and to increase the use of renewable energy to 20% by the year 2020, will lead to an increased use of biomass combustion, e.g. using wood logs and wood pellets. On the other hand, the Air Quality Directive (2008/50/EC) lies down stringent requirements on maximum levels of particulate matter in the ambient air. Solid fuel burning appliances and boilers produce particulate matter emissions which are of concern to authorities and the public. More particularly, the soot and organic components of these emissions are of most concern because they include compounds known for their potential impact on the human health and the environment. Moreover, part of ambient air particles is initially emitted as semi-volatiles (SVOCs), also named condensable fraction, and volatile organic compounds (VOCs) that form primary organic aerosols (POA) by condensation as the flue gas cools down, or secondary organic aerosols (SOA) due to photochemical oxidation into the atmosphere. Ambient measurements establish particle bound organic carbon as the largest carbonaceous fraction from wood burning emissions. It is important to note that the contribution of the condensable fraction to the emission depends on the quality of the combustion; the poorest the quality of the combustion, the highest its contribution to the emissions.
Different particle sampling procedures can be used to characterize emission from residential wood combustion, depending on the sampling method chosen, the condensable fraction will be taken into account or not. Two methods of measurements including the condensable fractions have been adapted from existing ones and compared to existing standards (US EPA 5H, Dilution tunnel, EN 13284-1, EN ISO 23210) and to each other. The first one consists of collecting the condensable fraction using cold impingers filled in with isopropanol and placed after a heated filter collecting the solid fraction. The second one consists of diluting the aerosol using a portable dilution device and combine it to online mass measurements using a tempered oscillating mass balance (TEOM) initially designed for ambient air mass measurements. The present paper will describe the adaptation and validation steps of the methods, the correlations obtained against existing standards as well as applications and perspectives of use in terms of emission factors determination, combustion characterization, and reduction techniques evaluation.

Goudeli Eirini / ETHZ

Agglomeration with polydisperse primary particles in the free molecular regime

Agglomeration of nanoparticles is encountered in atmospheric and industrial processes as for example in volcanic plumes and aerosol manufacture of carbon black or fumed silica. Here, ballistic agglomeration of clusters with varying polydispersity of the constituent primary particles (PP) is simulated by discrete element modeling[1] in the absence of coalescence, sintering or surface growth. Increasing the width or polydispersity of the PP size distribution increases initially the coagulation rate delays the attainment of the asymptotic agglomerate structure and self-preserving size distribution. For example, the standard asymptotic mass fractal dimension, D_f, by ballistic cluster-cluster agglomeration of 1.91 is attained with clusters containing more than 6 monodisperse PPs (geometric standard deviation of $\sigma_{g,PP}$ = 1) and more than 155 polydisperse PPs having $\sigma_{g,PP}$ = 2.5. The crossover size is defined here as the minimum PP number of agglomerates having the asymptotic fractal dimension. Agglomerates smaller than the crossover size exhibit a D_f and mass-mobility exponent D_{fm} between 3 and the asymptotic value of D_f = 1.91 and D_{fm} = 2.15[2], respectively. This transition to the fractal regime with increasing agglomerate size is consistent with mass-mobility measurements. Only the asymptotic prefactors (lacunarities) of the D_f and D_{fm} scaling increase with PP polydispersity and can be used to distinguish between different PP $\sigma_{g,PP.}$

The polydispersity of the PP size distribution affects also the intermediate agglomerate size distributions and kinetics. The agglomerates of monodisperse PP rapidly reach their self-preserving size distribution (SPSD), while for a PP size distribution (PPSD) with $\sigma_{g,PP}$ = 3.0, the r_g distribution becomes even broader than the initial PPSD. This is due to collisions between compact agglomerates or large spherical particles with small particles that hardly affect their mass. Furthermore, the width of polydispersity of the PP size distribution does not affect the asymptotic number concentration and overall collision frequency, even though it affects the agglomerate radius of gyration, mobility radius and volume-equivalent radius.

1. Goudeli, E., Eggersdorfer, M. L., and Pratsinis, S. E. (2015). Coagulation – Agglomeration of Fractal-like Particles: Structure and Self-Preserving Size Distribution. *Langmuir*, 31: 1320-1327.
2. Goudeli, E., Gröhn, A.J. and Pratsinis, S.E. (2016). “Sampling and dilution of nanoparticles at high temperature”, *Aerosol Science & Technology*, in press.

Gruenzweig Christian / PSI Villigen Switzerland

Three-dimensional visualization of soot, ash, urea and coating distributions in canned exhaust after-treatment components by neutron tomography

Neutron imaging is an alternative non-destructive inspection technique compared to the well-known X-ray method. Although neutron imaging data look at a first glance similar to X-ray images it must be underlined that the interaction mechanism of the sample material with neutrons differs fundamentally. X-ray interaction with matter occurs with the electrons in the atomic shells whereas neutrons interact only with the atomic nuclei. Hence, both methods have a different and therefore complementary contrast origin. Neutron imaging allows for a higher penetration through heavier elements (e.g. metals) whereas a high contrast is given for light elements (e.g. hydrogen, carbon).

By the use of neutrons instead of X-rays exhaust after-treatment systems can be successfully examined non-destructively for their soot, ash, urea and coating distributions. The big advantage of neutron imaging is that detailed, high-contrast images can be obtained even in canned substrates (silicon carbide or cordierite). Neutron imaging can be applied to substrates of passenger cars, trucks and even heavy duty vehicles. We can offer a maximum field of view up to 400mm x 400mm and a spatial resolution down to 13,5 µm/pixel. Neutron imaging was successfully used in the past to investigate diesel passenger car particulate filters for their soot and ash deposits [1].

This talk will briefly outline the method of neutron imaging and its advantage and complementary character compared to the conventional X-ray method. We will present further application areas of neutron imaging for exhaust after-treatment components. Especially, we focus on recently obtained neutron tomography results of gasoline particulate filters (GPF) and diesel particulate filter (DPF) concerning:

- Ash distribution in a canned passenger car GPF
- Urea distributions in passenger car DPF
- Ash residuals of a truck DPF after cleaning with different techniques

[1] C. Grünzweig, D. Mannes, A. Kaestner, M. Vogt.
Visualizing the soot- and ash distribution in diesel particulate filters using neutron im aging. MTZ 73(4):326 (2012).

Gülder Ömer / University of Toronto

The effect of combustion pressure on primary soot particle size in methane-air diffusion flames

Particle size and morphology of soot aerosols are crucial parameters in evaluating and appraising the influence of soot on the wellbeing of the humans and soot optical properties. As compared to the limited soot concentration measurements at pressures above atmospheric, measurements of soot morphology including the primary soot particle size at elevated pressures in tractable flames are scarce. Some of the information on primary soot particle size at elevated pressures has been obtained in diesel engine combustion in which isolating the effect of pressure is challenging. Some other soot particle size measurements at elevated pressures are from shock tube experiments.

Optical techniques, such as the light extinction and scattering as well as the laser-induced incandescence and the spectral soot emission, have been used routinely to measure soot concentrations in atmospheric flames. Laser-induced incandescence and light scattering have been proven to measure the primary soot particle size as well in atmospheric flames; however, using these two techniques for the purpose of primary soot particle sizing in diffusion flames at elevated pressures has been found to be problematic. One of the popular methods of studying soot morphology and primary size in atmospheric flames is thermophoretic sampling followed by transmission electron microscopy analysis.

A high pressure thermophoretic sampling system was built and used successfully to measure the size of primary soot particles in laminar diffusion flames of methane at pressures above atmospheric. The multi-probe sampling system was fitted inside the high-pressure combustion chamber that had been used previously for high-pressure soot formation studies. Soot samples taken at various pressures were analyzed subsequently by transmission electron microscopy to estimate the primary soot particle sizes. The soot volume fractions and soot temperatures were measured by spectral soot emission technique at the same height above the burner rim as the thermophoretic sampling. The mean primary soot particle size, measured at a constant height from the burner exit at all pressures, decreased about 35% from 2 to 10 atm whereas the soot volume fraction increased by a factor of more than 50.

Experimental results of mean primary soot sizes and the corresponding soot volume fractions imply that the number of soot nuclei in soot inception region of the laminar diffusion flames must have a strong sensitivity to pressure. The higher amounts of soot are mainly determined by the increasing primary soot particle number densities as the pressure is increased. The decrease in the rate of coalescence with increasing pressure might be the culprit in decreasing mean primary soot particle size as a result of the Knudsen number changing from about 20 at 2 atm to about 5 at 10 atm within the transition regime.

Hagen D. / Missouri University, USA

Updates to System Loss Correction Model for Jet Engine Exhaust Measurement

Jet engine exhaust emissions in the atmosphere are causing increasing concern in terms of their environmental impact, particularly their effect on the air quality around airports. The growth of commercial air traffic over the last decade has led to an increased contribution to the local inventory of gaseous and particle emissions from the operations associated with airports and aircraft engines. An accurate assessment requires that the number concentration and size distribution of the aerosols within engine exhaust and aging plumes be understood and well characterized. The near field jet engine exhaust plume is a dynamic environment, initially at high temperature and rich in small soot particles and relatively high concentrations of water vapor and reactive trace gas species, which then cools by mixing with ambient air promoting gas-to-particle conversion processes leading to dramatic changes in the composition and size distribution of the resulting aerosol. The Missouri University of Science and Technology (MST) Center for Excellence for Aerospace Particulate Emissions Reduction Research has led numerous jet engine exhaust sampling campaigns to characterize the number concentration and size distribution of PM emissions at different locations in the expanding exhaust plume ranging from the engine exit plane to as much as 150m downstream of the engine.

The SAE E-31 committee is currently developing an Aerospace Recommended Practice (ARP) for the measurement of non-volatile particulate matter mass and number-based emissions from the exit plane of aircraft gas turbine engines based on SAE Aerospace Information Report 6241. Particle loss, due to various mechanisms, occurs in the sampling train that transports the exhaust sample from the engine exit plane to the measurement instruments, since PM have a stronger tendency to stick to the wall of the sampling line upon collision as compared to inert gas molecules. For particle sampling from gas turbine engines, the most significant particle losses are due to thermophoresis (particles are forced to the tube wall when the wall is cold and the gas is hot) and diffusion. Thermophoretic losses are nearly independent of particle size, whereas diffusional losses increase with decreasing particle size. To account for the losses, both the size dependent penetration functions and the size distribution of the emitted particles need to be known to determine corrections to the measured mass and number of the particle emissions. In the proposed ARP particle number and mass are measured, but size is not measured due to difficulties in method standardization and traceability. A procedure for the calculation of sampling and measurement system penetration functions and system loss correction factors (SAE AIR 6504), without using direct size measurement has been under development for several years; here we present an overview of the methodology and its performance. A lognormal size distribution is used to represent the exhaust aerosol at the engine exit plane and is defined by the measured number and mass at the downstream end of the sample train. The results of this system loss correction are compared to corrections using size distribution information for a range of reasonable engine exhaust plane aerosols.

Hama Sarkawt M.L. / University of Leicester, UK

Temporal Variations of Lung Deposited Surface Area (LDSA) concentrations in Leicester

Ultrafine particle surface area has recently been considered as a potential metric in an effort to associate particle physical characteristics with health effects. In order to deliver contribution to such studies, the temporal and seasonal variations of lung deposited surface area (LDSA) with Black Carbon (BC), Total particle Number (N_{TOTAL}), Nitrogen Oxides (NO_X) concentrations were measured simultaneously at an urban background site in Leicester (UK) between November 2013 and Dec 2014. The study presents the results from an experimental investigation into the LDSA, BC, N_{TOTAL} and NO_X 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. A Nanoparticle Surface Area Monitor (NSAM, TSI 3550) was used to measure the LDSA (reported as $\mu m^2\ cm^{-3}$) corresponding to the alveolar region of the lung. The operating principle is based on diffusion charging of sampled particles. The BC was measured by MAAP (Thermo-5012), The N_{TOTAL} were measured by a water-based condensation particle counter (W-CPC) (TSI model 3783), and the NO_X by NO-NO2-NOx monitor (Thermos Scientific 42i). The overall average LDSA concentrations in cold (November-March) and warm (April-October) periods in Leicester were 37-39, and 20-23 $\mu m^2\ cm^{-3}$, respectively. LDSA correlates well with the other traffic pollutants (BC and NOx). Seasonal variation correlation between LDSA and the other parameters (N_{TOTAL} as an example) were observed (as shown in Fig. 1). The correlation considerably increased when only using cold period data, particular winter data. In addition, the influence of metrological parameters (particularly wind speed and direction) on LDSA will be detailed. Overall, the results support the notion that local traffic emissions were a major contributor of the atmospheric LDSA and a clear seasonal variation was found, with higher values during cold period.

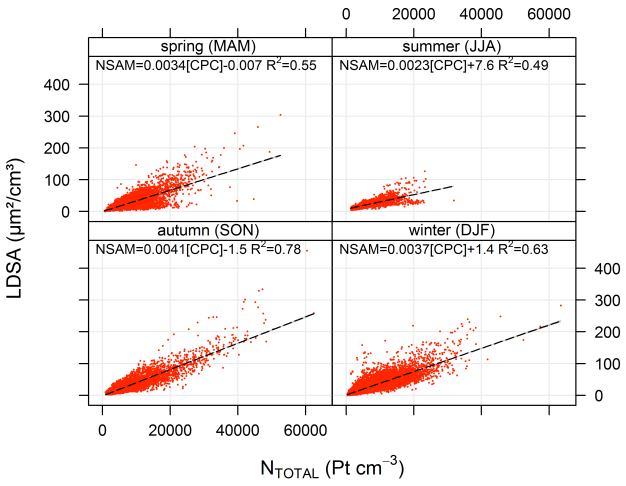


Figure 1: Correlation between LDSA and N_{TOTAL}.

Haralampous Onoufrios / TEI of Thessaly, Greece

Measurement and Modelling of PM Loading in Bare and Catalytic Flow-Through Monoliths

The honeycomb monolith is the most prevalent geometry in automotive exhaust aftertreatment, with applications covering oxidation catalysts, partial-flow and wall-flow filters. Particle collection mechanisms at the leading edge of honeycomb monoliths and in open channels are usually neglected by engineers of these devices. Under specific conditions however, these phenomena can make an appreciable contribution to overall particle collection and deposits on channel walls may affect catalyst performance.

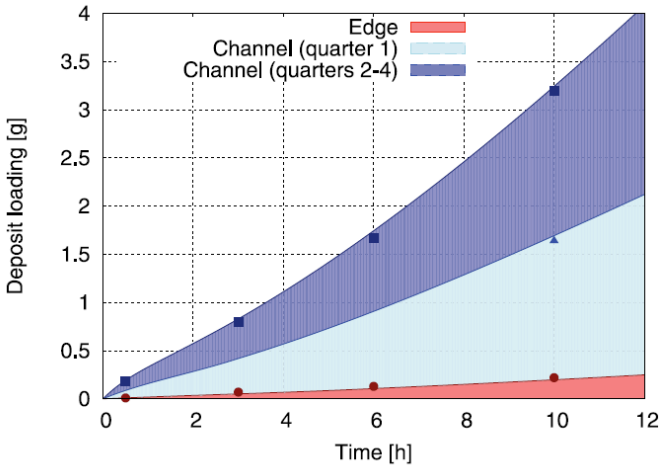


Fig. 1: Computed deposit mass distribution (lines) versus experimental (points) as a function of time [2] for a bare 600 cpsi monolith.

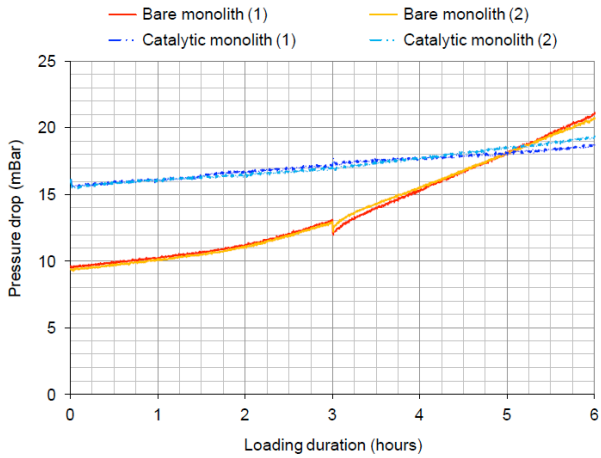


Fig.2: Measured backpressure evolution during PM loading of bare and catalytic monoliths [1].

Available deposit loading tests [1] conducted with a Diesel Particle Generator are used in this study to highlight the differences in capture efficiency and deposit evolution between bare and catalytic flow-through monoliths. The experimental measurements include particle distribution at the inlet, recordings of backpressure in the flow-through monoliths and deposit weighting. Furthermore a recently developed diesel particle collection model [2] is extended to take into account the reaction of soot and diffusion of gaseous species in the deposit layer. The deposit balance includes the most important collection mechanisms taking into account

particle size and a depletion term due to soot reactions .As a result, the model is able to predict the temporal and spatial variation of deposit loading inside the channel and at the leading edge of the channel, as shown in Fig. 1.

The measured backpressure evolution during loading of bare and catalytic monoliths is shown in Fig. 2. The coated monoliths present considerably higher backpressure at clean state, however the pressure drop increase is comparatively very small during the loading test. These differences reflect the effect of washcoat on pressure drop, particle collection and deposit reaction, which is further analyzed and quantified with the mathematical model. Finally the negative effects of deposits on the catalytic performance are also discussed.

[1] Payne S. D. Experimental studies of diesel particle filtration. PhD Dissertation, University of Cambridge, UK, 2011
[2] Haralampous O., Payne S., "Experimental Testing and Mathematical Modelling of Diesel Particle Collection in Flow-Through Monoliths", Journal of Engine Research, DOI: 10.1177/1468087416637735, 2016

Hartmann Ingo / DBFZ Germany

Micro-scale biomass combustion system with very low emission

The use of biomass for heat production in small scale combustion systems provides an on-site energy supply from renewable resources. Low pollutant emissions as well as heat output on demand are the basis for the application of environmentally friendly and efficient systems. In line with improved thermal insulation of buildings heat production furnaces in the low power range gain relevance. The formation of pollutants during the operation of biomass combustion systems is not completely avoidable. Especially for low power systems, the adjustment of optimal combustion conditions is difficult. Insufficient or excess air supply as well as fuel overload lead to high concentration of pollutants. In small-scale biomass combustion this may be caused by the incorrect operation of the systems. Moreover, high concentrations of pollutants occur due to incorrect air supply and the inappropriate system dimensions for the combustion process during part load operation. In addition, the achievement of a low pollutant concentration with non-wood biomass is often not solely possible by a proper design of the combustion process in small-scale systems. According to this, the performed investigations refer to two key aspects. On one hand the pollutant formation dependent on air and fuel supply and on the other hand emission reduction measures are analyzed. By this manner, the original conditions and the emission reduction potential as well as the required improvements of the combustion process are observed. Investigations have been carried out at a micro-scale combustion system with a heat output between 1 and 2 kW. Comminuted wood pellets were used as fuel. The pollutant formation under different combustion conditions was observed by variation of primary and secondary air supply. In this manner, the combustion with excess and deficient air was investigated amongst others. The particulate matter emissions (PME) were measured with a Scanning Mobility Particle Sizer (SMPS) and Total Suspended Particles (TSP) were measured according to method VDI2066. The flue gas composition was measured by a Fourier transformation infrared spectroscope (FTIR), a flame ionization detector (FID) and a paramagnetic oxygen analyzer. Also the influence of the air supply on nitrogen oxide concentration was monitored. Beside primary combustion modification, also the integration of catalysts can improve the conversion of the combustion gas to carbon dioxide and water. The combustion system with the combustion chamber in form of a cylindrical reactor allows the integration of catalysts in different temperature zones. The differentiation between the effects relating to the catalytic activity of the material and the changes of process parameter can be investigated using monoliths with and without the catalytic active compound. With this combustion apparatus very low emissions are measured. TSP and carbon monoxide were below 5 mg/m³ in a lambda range from 1.1 to 2.2. On this basic development a transcription and scale-up to a prototype pellet burner unit was carried out. With this prototype the emissions are in the same range as for the lab scale system.

Hildebrandt Mrgit / Physikalisch-Technische Bundesanstalt Germany

Analysis of a new diesel soot generator with regard to particle size and number concentration

The influence of soot particle emissions on earth´s radiation budget and human health leads to a persistent tightening of European limit values for engine exhaust emissions. These regulations also promote the development of new techniques for measuring soot particle properties which in turn has to be supported by a manufacturer independent infrastructure for validation and calibration. This means the characterization of particle counters and classifiers under metrological criteria regarding particle number concentration and size distribution and the traceability to SI units. Here, the choice of a proper calibration aerosol plays an important role, as the function of the instruments is strongly influenced by chemical and morphological aerosol parameters. The calibration aerosol should resemble the particle characteristics of the emission source to avoid systematic deviations. The characteristics of engine exhaust particles, however, are known to depend on engine type, its operation conditions and in particular on engine fuel. Up to now, reference type soot generators – most often diffusion flame burners based on propane combustion - are considered suitable as soot aerosol source for calibration purposes because of their stable and reproducible soot generation properties. But several studies indicate significant differences between engine and propane flame soot particles with respect to agglomerate density and surface. A solution to minimize aerosol morphology and composition differences could be the use of a lab generated combustion of real diesel fuel which is realized by the newly developed Diesel-miniCAST (Model 5201 Type D, Jing Aerosol Ltd.) based on a premixed flame matrix.

On this poster, early results of the Diesel-miniCAST characterization by variations of the diesel supply and other gas flows inside the burner are presented as well as the influence of thermal treatment on the soot particles. First results of the measurements from the diesel soot generator prototype show a range of mean particle diameters from 60 to 160 nm with number concentrations up to 3 × 105 cm-3. The midterm goal is to develop a metrological diesel based soot aerosol transfer standard for the calibration of instruments used for particle number concentration measurements from engines and to generate a secondary calibration aerosol for the calibration of particle counters and classifiers at the PTB, the German Metrology Institute.

Horn Hans-Georg / Consultant for TSI

Calibration of Engine Exhaust CPCs: Measurement Uncertainty Following ISO 27891 Procedures

The condensation particle counter (CPC) is an established instrument in regulated measurements including the certification of new vehicles and combustion engines. Quality control in regulated measurements requires traceability of instrument calibration. ISO 27891 /1/ - a new International Standard for the calibration of CPCs - together with EMRP-ENV02 /2/, a meanwhile completed research project of several National Metrology Institutes lay the ground for SI-traceable calibration of CPCs and standardized reporting of measurement uncertainty.

For many years, TSI has calibrated its engine exhaust CPCs following the requirements of UN-ECE Regulations 49 and 83, and GRPE-PMP. To further improve this practice, TSI is currently finalizing the implementation of ISO 27891 for the measurement of the detection efficiency of engine exhaust CPCs. Part of this process was to perform a series of test calibrations /3/ following the new standard. Since ISO 27891 offers a standardized way to determine the calibration measurement uncertainty, the data obtained during the test calibrations form a solid base for the uncertainty evaluation.

Major uncertainty components for the calibration of CPCs are

- the calibration uncertainty of the instrument used as number concentration reference; either a Reference-CPC or a Faraday-Cup Aerosol Electrometer (FCAE),
- the measurement uncertainty related to the split of the calibration aerosol flow between the instrument under calibration and the reference instrument,
- the measurement uncertainty of the inlet flow rate of the CPC under calibration, and
- the repeatability of the measurement of the detection efficiency of the CPC under calibration.

When calibration measurements are made in the size region where the CPC's efficiency curve drops towards zero (e.g. when measuring the detection efficiency of an engine exhaust CPC at 23 nm), the contribution of the calibration particles' size uncertainty should also be considered.
The contributions of all above mentioned components to the measurement uncertainty of the calibration of engine exhaust CPCs will be quantitatively discussed in the presentation. Combining all data obtained during the implementation test series demonstrates that the expanded measurement uncertainty (k=2) for the calibration of engine exhaust CPCs against a Reference-CPC - which itself is calibrated against a Master-Reference-FCAE - is in the range of 4 to 5 %.

/1/ *ISO 27891 (2015)* - Aerosol particle number concentration — Calibration of condensation particle
counters
/2/ *Novak, A. and Andres, H. (2014*) - Measuring Soot Particles from Engines: Recommendations from
EMRP-ENV02 Project in WP1. 18th ETH Conference on Combustion Generated Nanoparticles,
June 25th, 2014
/3/ *Horn, H.-G. and Gladis, D. (2015)* - First Experiences and Results Implementing ISO 27891 for CPC
Calibration

Im DongGuk / Korean Register of Shipping

Particulate Emission Characteristics of Two Stroke Marine Diesel Engine

International Maritime Organization has been regulating various pollutants produced from ships for marine environment protection as well as responding to global climate change. Especially, the regulations of NOx and SOx emissions emitted from ship engine for reducing air pollutants are more stringent. In case of particulate emission, it has been indirectly regulated by sulfur contents of fuel oil, but Marine Environment Protection Committee of IMO is discussing the regulation of black carbon, one kind of particulate emissions from ship. Moreover, black carbon has recently been categorized as major contributor to global climate change. In this study, we analyzed the characteristics of particulate matters(PM) emitted from two stroke diesel engine. The rated power of this engine classified as a low speed engine is 7,400 kW at 129 rpm (Hyundai - MAN B&W 6S46MC-C7). Low-Sulphur fuel (bunker A; 0.29 % S) was utilized in this study and tests were carried out under steady-state operating conditions of ISO E3 cycle. The mass concentration of particulate emission measured with particle sensor and the number concentration measured by means of dilutor and particle sizer (0.01 ~ 10㎛). The results revealed that particle mass concentration decreased with decreasing engine speed and load. Particle number concentrations with particle size were varied with engine operating conditions. In case of nucleation mode particles (d< 50 ㎚), the number concentration under full load condition was higher than that under relatively lower speed and load conditions. Coarse mode particles (d> 1 ㎛) decrease with decreasing engine speed and loads. These results are helpful to development of abatement technology for reduction of particulate emission emitted from two stroke diesel engine as well as four stroke diesel engine because the strategy for reduction of particulate emission may change in number concentration with particle sizes and particulate mass concentration under various operating conditions.

Fig. 1 Photo of Two stroke diesel engine Test bed at KR TCC(Test & Certification Center)

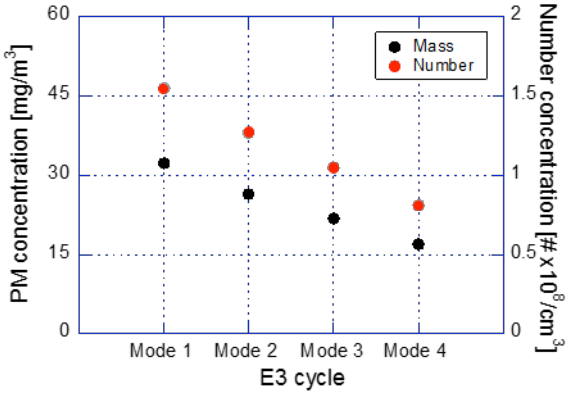


Fig. 2 PM mass and number concentration under 4 modes of E3 cycle

Iwasaki Kentaro / Sumika Ceramics Poland

DPF design concept and catalyst coat-ability investigation

An emission technology among automotive industry is one of the key parameters to realize sustainable society. A Diesel Particulate Filter is one major system to contribute for emission regulation under expanding atutomotive industry, and its functionality is increasingly demanded not only for PM but also for NOx reduction in upcoming certification mode of RDE while fuel penalty related to CO2 reduction needs to be improved. One of the function requirements for next generation DPF is regarded as lower backpressure even with high amount of catalyst loading. A novel-designed DPF consisting of aluminum titanate ceramics materials with high thermal durability and unique channel geometry based on hexagonal structure has been developed to realize functional after-treatment devices. The basic concept of hexagonal channel design could be from lower backpressure under soot-loading stage and higher ash-capacity related directly to the longer periods of DPF usage. The structure has recently been progressed to create more surface area to accumulate the catalyst material inside inlet channel of DPF through the wavy-wall technology. It has been named as 'microgear' design. Previously the advantage of backpressure properties with this wavy –wall design has been revealed under soot-loading process because of its higher specific area to accumulate the soot-cake which enables the soot-layer thinner, and its permeability of wall and deposited soot-layer higher. Additionally, a model-coating study indicated the creation of higher surface pore after high wash-coating resulting in lower transient backpressure with lower gas velocity in wall-through process. Herein, the highlight is the dependence of coat-ability for this wavy-designed hexagonal DPF on backpressure compared to normal wall one as a reference. It was interestingly shown that coating location improves backpressure response. The microscope observation indicated the wash-coat status deposited on the way wall influences the soot-cake formation corresponding to backpressure behavior. Thus-obtained output among wavy-wall structure should be useful for its indication of other functionality such as catalyst performance while the related-study is underway.

Jaliliantabar Farzad / Tarbiat Modares University Tehran

Investigation of waste cooking oil biodiesels effects on performance and emissions in a CI engine

One of the most challengeable demands of human beings in all of the history has been energy. In the 20th century due to industrialization this issue became more problematic. The growth in price of common energy sources especially in recent years, enforced human to use alternative sources of energy (Ashnani, Johari, Hashim, & Hasani, 2014). In addition, spread of pollution caused by fossil fuel consumption signals the necessity to develop renewable energy sources with fewer effects on the environment such as biodiesel. Nowadays biodiesel s one of the most popular substitution or additive for diesel fuel. In this study, primarily different blends of diesel biodiesel (B0, B5, B10, B15 and B20) of waste cooking oil have been considered on an air cooled 4 stroke engine in various engine speeds (1700, 2100, 2500 and 2900 rpm) and loads (0, 25, 50, 75 and 100%). Then, effect of this factors on engine have been evaluated by its performance (engine power, torque, specific fuel consumption (SFC) and exhaust gas temperature) and emission (CO, CO_2, HC, NO_x, k value) parameters. The result of the sensitivity analysis showed that the most effective parameters on the engine performance and emissions is the engine load. , it is found that the most emissions decreased while using biodiesel fuel in the engine. The highest reduction was for $NO_x$and HC emissions, 94.55% and 52.37%, respectively. The smoke opacity for biodiesel blends are lower than that of the diesel fuel. The highest value of k value reduction is for B5 fuel blends (44.29%) in 1700 rpm. Totally it can be stated that the k value for the all fuel blends in 1700 rpm have been decreased considerably regard to B0 (44.29, 40.21, 31.79 and 33.60 % for B5, B10, B15 and B20, respectively). As discussed in above section about correlation between k value and amount of CO, CO_2 and HC, the order of fuel blends for k value is same as that in mentioned emissions. So, the main reason for reduction of k value while using biodiesel diesel fuel blends is its oxygen content. This additive oxygen has improved the quality of combustion and hence decreased the HC and CO emissions. Increase in k value may be due to its higher viscosity and density than diesel fuel which may decrease the injection and mixing in cylinder of fuel. The result of this variation in injection and mixing is a low quality combustion and production of Co, HC and finally smoke. Same results are reported by other researchers (Buyukkaya, 2010).

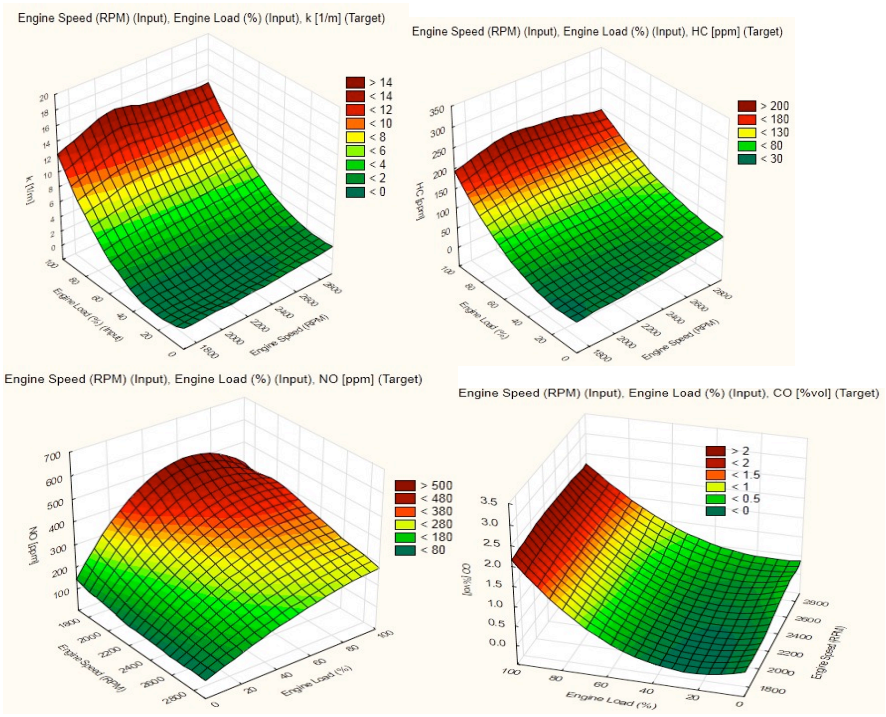
Table 1. Some important characteristics of the produced biodiesel fuel along with the related standards

Specification	Standard test method	Allowable range	Biodiesel	Diesel	Unit
Kinematic viscosity	EN 14214	3.5 - 5	4.72	3.5	mm^2/s
Density	EN 14214	----	0.862	0.837	g/cm^3

Figure 2. Engine test set up

Table 2. Specifications of the evaluated engine

Model	3LD 510
Manufacturer	Lombardini, Italy
NO. Cylinder	1
Piston stroke	90 mm
Cylinder diameter	85 mm
Cylinder volume	510 cm^3
Maximum power (at 3000 rpm)	12.2 hp (9 kW)
Maximum torque (at 1800 rpm)	33 N.m



Jang Jinyoung / Korea Institute of Energy Research

Nanoparticle from light duty vehicles using various fuels for FTP-75 and WLTC

In light duty vehicles, PM (particulate matter) from especially diesel vehicles has been a big issue due to health and environmental problems. And these days, nano-particles smaller than 23 nm are concerned due to its health effect including PM from GDI (gasoline direct injection) vehicles.

In this study, diesel and GDI vehicle as well as gasoline MPI, LPG and CNG vehicle were compared for PN (particle number). Test vehicles are diesel vehicle without DPF (diesel particulate filter) and with DPF, gasoline MPI (multi point injection), GDI, two different LPG (liquefied petroleum gas) vehicles and CNG (compressed natural gas) vehicle. In the case of CNG vehicle test, CNG vehicle's engine was started with LPG fuel and then fuel was changed from LPG to CNG when the coolant temperature reached 60^{o}C. FTP-75 and WLTC test mode were used and PN measuring were conducted in accordance with the PMP method. PN was measured by two different CPC at a time. Fist one is used for measuring over 23 nm PM count and another is for over 5 nm PM count.

Regardless of vehicle type, PN including sub 23 nm PM was higher than PN without sub 23 nm PM. Therefore, PN including sub 23 nm PM from test vehicles except for diesel vehicle with DPF was higher than 6 * 10^11 #/km. PN was usually increased at the cold start and then increased and decreased repeatedly by vehicle speed. Generally, PN from WLTC was higher than that from FTP-75. In the case of WLTC, PN was increased at the high speeding region. PN from diesel vehicle with DPF were lowest than PN from others due to DPF. PN from diesel vehicle without DPF were highest and PN from GDI was next. In the case of LPG and CNG vehicle, PN including sub 23 nm PM were much higher than PN without sub 23 nm PM at high speeding region of WLTC.

Järvinen Anssi / Tampere University Finland

Particle emission from loaders using normal and bio based diesel fuels

Diesel powered loaders are used for maintenance purposes in residential, industrial and commercial areas. Because these machines are operated in close proximity to people, their emissions can contribute to non-wanted health effects. We studied nanoparticle emissions from two different loaders (Wille 355b and 855c, Vilakone Oy) in case of EN590 B7 (diesel containing 7 % fatty acid methyl esters) and renewable hydrogen threated vegetable oil (HVO) based diesel fuels (both supplied by Neste Oyj) under real working conditions. The main focus was to study the effect of renewable fuel on the particle emissions of loaders.

Measurements were conducted using Portable Emission Measurement System (PEMS, Järvinen et al 2015), which worked as a platform for laboratory grade instruments. Two stage ejector dilution was used to extract the sample from the exhaust pipe. The first dilution stage was heated to 140 °C and the second stage was operated at outdoor temperature, approximately 15 °C. The total dilution ratio was approximately 150, primary being 9 and secondary 17. The PEMS and the measuring instruments were installed into a trailer towed by the machine. Particle number concentration was measured by a Condensation Particle Counter (CPC A20, Airmodus Oy) and the size distribution by an Engine Exhaust Particle Sizer (EEPS 3090, TSI Inc.). Exhaust particle mass concentrations were evaluated based on particle number size distributions.

The measurement cycle was chosen to simulate average use of these machines. It consisted of idle, loading, towing the trailer at a constant speed, and towing the trailer and a blasting carpet at a constant speed to simulate plowing of snow. These two driving stages were conducted twice during the measurement cycle and the entire cycle was measured twice for each loader and fuel combination.

In general, the exhaust particle concentrations reduced when the fuel was changed from EN590 B7 to HVO. In case of the larger 855c model, the particle number concentrations did not change significantly when the fuel was switched, but the mass concentrations reduced by 20% to 25%, when the HVO was used. In case of the smaller 355b machine, the particle number concentrations reduced from 10% to 40% by HVO, except in case of loading where higher number concentrations were observed. The mass concentrations reduced by 20% to 70% in all cases, when the fuel was changed to HVO. This is easily seen in the Fig. 1, which represents one measurement cycle for smaller 355b machine operating on both fuels. In general, the decreasing mass concentrations resulted from decrease in particle size, and in case of 355b, also from decrease of particle number concentration. For instance under high load driving, the mode of the particle diameter was approximately at 50 nm for EN590 B7 but only at 35 nm for HVO.

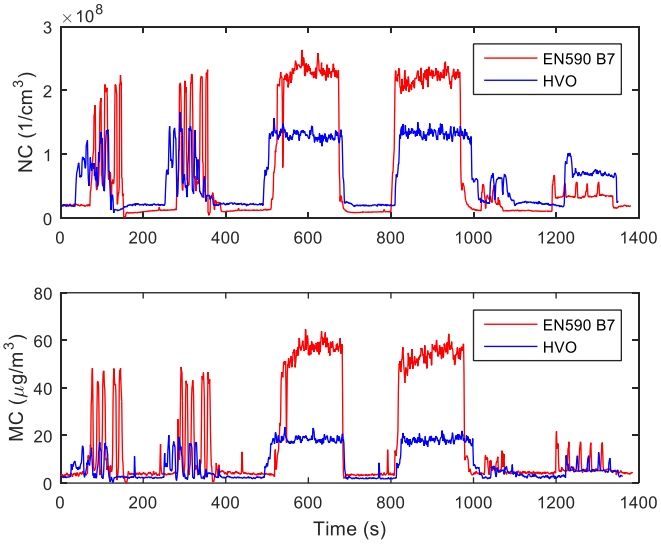


Figure 1. Measurement cycle for Wille 355b operating with both fuels. NC refers to particle number concentration and MC mass concentration (assumed density of 1 g/cm^3), both calculated to raw exhaust concentrations.

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Jasiński Remigiusz / Poland University of Technology, Poland

Dangers of nanoparticle emissions in the vicinity of airport

The issue of emissions from internal combustion engines attracted a lot of interest in the scientific community and engage the public because of the known association between exposure to multiple air pollutants and short and long-term consequences for human health. In addition, exhaust emission may affect the deterioration of visibility and directly or indirectly affect the climate.

Increasing knowledge of the processes related to emissions from aviation engines and the dynamic development of the measuring devices necessitate the creation of new rules and conditions for the certification of aircraft engines. The first emission standards for aircraft engines introduced in the late 70th century by the International Civil Aviation Organisation (ICAO).

The issue getting more significant is exhaust emissions from aircraft engines, especially particulate matter. Nowadays more and more attention is paid to the emissions in areas of airports, due to the rapid increase in the volume of air transport and the outlook for further development in order to meet transportation needs for the subsequent years. Although emissions of particulate mass have been studied since the beginning of the creation of emission standards, the question of particle number and their size distribution is a matter innovative.

The paper presents the issue of particulate emissions from passenger planes and their impact on air pollution in the vicinity of the airport. Studies were carried out in the area adjacent to the airport Poznan-Lawica. The measurement of particle concentration was performed four times during the landing of aircraft equipped with jet engines. Total concentration and size distribution of particulate matter were subject of analysis. It was found that during the single landing operation the concentration of PN increases several dozen-fold. The increased number of particulates in the air is maintained for a period of not less than 60 seconds. On the basis of the measurements a significant effect of aircraft on the concentration of particulates numbers in the area adjacent to the airport was found.

The measured particulate size distributions indicate that particulate matter emitted by the aircraft engines are characterized by a set of dimensions in the range of 5-40 nm. This fact is significant that these particles are the most harmful to human health. There were found significant differences in size distribution of PN depending on the type of jet engine. The older generation of engines emit particles with a size distribution similar to the distributions derived from automotive vehicles. Measurement were carried out at a distance of about 2 km from the touchdown of aircraft. It suggests that the areas of the runway, taxiways and aprons can be much more polluted than the area where the studies were conducted. This is particularly important in the context of ground handlling.

Jung Heejung / University of California

Alternative metrics for spatially and temporally resolved ambient particle monitoring

Particle active surface area is regarded as an important alternative metric to correlate particle emissions to adverse health effects. A mobile platform was installed on a gasoline vehicle and sampled particles on one of major highways in Southern California. Although the SMPS measurement provides particle size distributions (PSDs) that can be converted into many
important metrics, this method is impractical to implement for a routine monitoring over a wide
region. This study introduces an alternative method and new metrics using the condensation particle counter (CPC) and electrical aerosol detector (EAD). While each instrument monitors PN (particle number) and PS (particle surface area) concentrations, the ratio of PS/PN pro-vides
an additional information of particle size which is important for particle transport. PSDs measured by NanoScan SMPS on highway and by EEPS in the lab were used to verify the concept. The study found that alternative metrics (PN, PS, and PS/PN) can be used to moni-tor spatiotemporally resolved particle concentrations for a wide region.

Karjalainen Panu / Tampere University Finland

Non-combustion exhaust particles observed during decelerations of heavy duty diesel vehicles

Particle emissions from vehicles have been studied and regulated extensively due to the adverse health effects associated with emitted particles. Recent studies (Rönkkö et al., 2014; Karjalainen et al., 2014) have observed vehicle nanoparticle emissions during engine braking while fuel consumption is zero. New road diesel engines are equipped with diesel particle filters (DPFs) in Europe and the US, whereas there are no particle filters in the majority of heavy-duty vehicles currently on the road. With particle filters the particle emissions during engine braking are considered negligible whereas for the vehicles without the filters these emissions are reality. Here two heavy-duty diesel vehicles operating in the Helsinki (Finland) area were studied in terms of particle emissions under controlled acceleration/deceleration patterns (Karjalainen et al., 2016).

Two vehicles (Table 1) were tested in the heavy-duty chassis dynamometer facilities of VTT. Test runs consisted of repeatable controlled 40-20 km/h and 80-20 km/h deceleration events and the standardized World Harmonized Vehicle Cycle (WHVC) test. The acceleration/deceleration pattern was used in order to study the phenomena related the particles during engine braking in detail, and the WHVC to estimate engine braking related particle emissions over a standardized driving routine.

Table 1. Details of studied heavy-duty vehicles.

Vehicle	Year	Emission level	Emission control	Transmission
Bus	2005	Euro III	EGR	Automatic
Truck	2007	Euro IV	EGR+DOC	Manual

The particle sampling was executed with a system consisting of a porous tube diluter, an ageing chamber and an ejector diluter. Exhaust particles were measured in real-time with condensation particle counters (CPCs), a high-resolution low pressure impactor (HRLPI) and an engine exhaust particle sizer (EEPS). The particle volatility was studied utilizing a thermodenuder at 265°C. Exhaust particles were also collected during engine braking and later analyzed with a transmission electron microscope (TEM).

An example of particle emission profiles measured by the CPCs (top) and EEPS (center) are shown in Figure 1 during the 40-20 km/h test for the truck. The particle concentration levels were comparable between accelerations and decelerations but the particle size was different. During deceleration conducted by engine braking the particle GMD was close to 20 nm, and both the particle size and number concentration decreased with time.

Particle emission levels during engine braking were found to correlate with engine coolant and oil temperatures. TEM images revealed that the particles collected under engine braking conditions contained similar ash compounds found in the lubricant oil. Also it was found that the gear changes during deceleration increased the amount of emitted particles. This can lead to excess particle emissions caused by often gear shifts with automatic transmission. Additionally, in fact, during combustion of fuel (accelerations, steady speed) the detected nucleation mode was very similar as observed during engine braking.

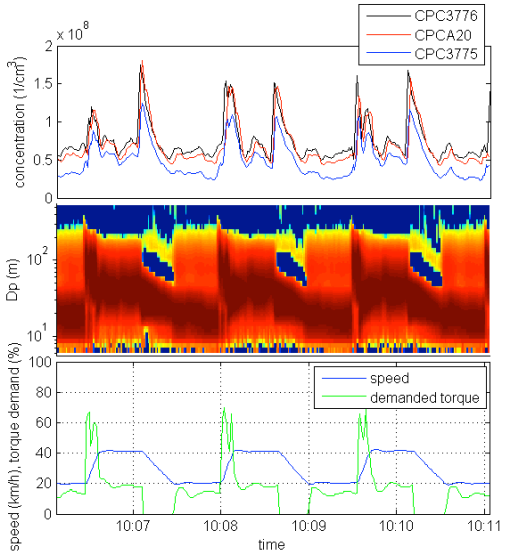

Figure 1. Exhaust particle number concentrations measured by the CPCs (top), size distributions measured by the EEPS (centre), wheel speed and driver's demanded torque (bottom). Cut-sizes in CPCs were: 2.5 nm (CPC3776), 7 nm (CPCA20) and 23 nm (CPC3775, tuned).

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Kato Kyohei / NGK Europe Germany

Gasoline Particulate Filter Technology – Readiness for Real Driving Emissions

Gasoline Direct Injection (GDI) concepts are the key technology of gasoline engine development to reduce CO2 emissions while improving torque and power output. However the drawback of GDI engines are increased particle number emissions compared to conventional Port Fuel Injection (PFI) engines. For compression ignition (Diesel) engines a particulate number (PN) limit of 6E11 #/km was already introduced with the enforcement of Euro 5b (09/2011). In addition a particulate mass (PM) limit of 4.5mg/km was introduced. The Euro 6b legislation also covers a PN/PM limit for GDI engines effective since 09/2014. During the first three years of the introduction the manufacturer is permitted to apply a higher PN limit of 6E12 #/km. Finally a stricter limit of 6E11 #/km will become effective for all passenger cars and light duty trucks from 09/2017 (Euro 6c).
Most of the GDI particles are formed during cold start phase, catalyst heating mode and dynamic engine modes. Therefore the injection system including injection operating program has been further developed in order to improve air–fuel mixture in the cold start phase. Furthermore, internal engine measures such as improved mixture homogenization and minimized amount of injected fuel striking the walls help to avoid the formation of particles. Thus latest GDI vehicles can achieve the PN limit of 6E11 #/km during the New European Driving Cycle (NEDC).
In addition to the PN limit in the NEDC, the European Commission is considering to implement a Real Driving Emission (RDE) certification for Euro 6c. RDE will also include particle counting, which would require stable and low engine out PN emissions in a wide range of engine map operation. While GDI engine development progresses further, a particulate filter is one of the technological solutions to reduce PN from GDI engines effectively and reliably. In case of a Diesel engine, the Diesel Particulate Filter (DPF) is an established emission control technology to reduce soot emissions for several years. Thus the DPF design builds the cornerstone of the GPF development in order to reduce particle emissions from GDI engines. One concern is the impact of a GPF on the pressure drop (PD) of the exhaust aftertreatment system, and therefore, potentially higher CO2 emissions. In addition sufficient Filtration Efficiency (FE) for particles is needed to meet the PN emission regulation. Hence minimizing GPF's pressure drop is of paramount importance for the development to achieve the long-term CO2 targets of 95 g/km beyond 2020.
The aim of this paper is to discuss the GPF performance under real driving conditions, how the performance might be affected by the future EU 6c regulations and how to optimize the filter design parameters to accomplish best performance of the GPF as one component of the exhaust aftertreatment system.

Kelesidis G.A. / ETHZ Switzerland

Control of Particle Structure & Size Distribution by Humidity

Humidity affects significantly the impact of atmospheric aerosols, such as soot, on public health and environment by changing their structure and size distribution (Weingartner *et al.*, 1997). The fresh fractal-like soot aggregates become more compact after condensation and evaporation of water, as their primary particles restructure to form a sphere. Furthermore, water vapor shifts the aerosol size distribution to smaller mobility sizes (Ma *et al.*, 2013). This aggregate restructuring by humidity could be used also in flame-made material synthesis to produce small and compact nanoparticles with well-defined size distributions. These characteristics are attractive for biomedical applications, where polydisperse aggregates with open-like structures, such as silica, are currently used (Sotiriou *et al.*, 2014).

Here, the effect of humidity during sampling and diluting flame-made silica nanoparticles is investigated. Water vapor produced by an evaporator is introduced in the sampling line through a torus ring. The humid aerosol flow passes through two diffusion dryers to remove the condensed water. A simple model is developed to estimate the saturation ratio, S, after mixing the aerosol flow with water vapor. The model is validated with temperature and relative humidity measurements for $S < 1$, within the detection limit of the gas sensor. Then, S is varied from 1.1 to 1.75 by changing the evaporator's process conditions.

Combined Differential Mobility Analyser (DMA) and Aerosol Particle Mass (APM) measurements are used to determine particle structure and anisotropy by the mass-mobility exponent, D_{fm}, and prefactor, k_{fm}, respectively. Silica nanoparticles restructure and become almost spherical and symmetric, since D_{fm} increases from 1.98 ± 0.18 for dry conditions to 2.75 ± 0.14 for $S = 1.75$, while k_{fm} decreases from 1.7 ± 0.99 to 0.43 ± 0.16. The evolution of D_{fm} in terms of S is compared to experiments of soot undergoing condensation and evaporation of water (Ma *et al.*, 2013). The respective mobility size distributions measured by DMA are narrower and shift to smaller mobility sizes. Relationships describing the reduction of mean aggregate mobility diameter and geometric standard deviation in terms of S are proposed and compared to those for soot (Weingartner *et al.*, 1997; Ma *et al.*, 2013).

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Kelesidis Georgios A. / ETHZ Switzerland

Nascent Soot Formation by Agglomeration and Surface Growth

Soot can be classified in two categories based on its formation stage, namely nascent (particles of 1-10 nm mobility diameter) and mature soot (fractal-like aggregates with mobility diameters between 10 and 100 nm). Nascent soot particles have been observed in a wide range of combustion sources, from laminar diffusion and premixed flames to diesel engines (Dobbins, 2007). There are major concerns, however, about the adverse effects of nascent soot on public health due to their small size and high specific surface area (Pedata *et al.*, 2015). Thus, a better understanding of nascent soot formation is required for identification of process parameters that determine soot size and morphology.

Here, nascent soot growth is investigated by Discrete Element Modeling (DEM) of agglomeration and surface growth (SG) during acetylene pyrolysis. The model is validated with theoretical expressions for pure agglomeration (Goudeli *et al.*, 2015) as well as with SG with and without coagulation at full coalescence. The evolution of nascent soot structure is benchmarked against previous numerical studies (Morgan *et al.*, 2007).

Nascent soot growth by agglomeration with or without SG is compared to that with full coalescence. Neglecting the fractal-like nature of soot underestimates its mobility diameter, d_m, and polydispersity up to 40 %. The DEM-obtained size distributions of soot growing by agglomeration with SG are in good agreement with microscopic (Schenk *et al.*, 2013) and mass-mobility measurements (Camacho *et al.*, 2015) in a standard burner-stabilized stagnation ethylene flame.

The evolution of nascent soot structure from spheres to aggregates is quantified by mass fractal dimension, D_f, and mass-mobility exponent, D_{fm}. Soot particles are quite spherical for d_m < 6 nm where SG is dominant, consistent with Schenk *et al.* (2013). When SG ends and agglomeration starts to prevail, D_f and D_{fm} start to decrease as more open and rather elongated structures are formed. New soot layers are formed on the primary particle surface by acetylene SG and bury the original primary particle boundaries, making the aggregates more compact & eventually spherical. The DEM-derived D_f and D_{fm} are in excellent agreement with microscopic (Schenk *et al.*, 2013) and mass-mobility measurements (Camacho *et al.*, 2015), pointing out the capacity of the present model to accurately capture soot dynamics by agglomeration and surface growth (SG).

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Keller Alejandro / University of Applied Sciences Northwestern Switzerland

Time-resolved secondary organic aerosol formation potential of wood burning emissions

Wood burning (WB) is a major contributor to pollution by carbonaceous particulate matter. At certain locations in Western Europe, it surpasses many-fold the contribution from fossil fuel (Szidat et al., 2007). Ambient studies have found organic carbon (OC) to be the largest carbonaceous fraction from these emissions. In turn, the secondary organic aerosol (SOA) produced by atmospheric aging may amount to more than 50% of the atmospheric OC related to this type of combustion (Lanz et al., 2007). This makes wood burning SOA one of the most important atmospheric pollutants in Europe (van der Gon et al., 2014).

We use the micro smog chamber (MSC), a continuous-flow reactor-tube (Keller & Burtscher, 2012), to produce photochemical aging and generate SOA within seconds. This process is essential to fully capture the potential impact of the emissions, which is by far not reflected by the current standards. Using our setup, we have studied the emissions of different combustion appliances from small (7kW) batch-operated logwood stoves to medium size (up to 450kW) automatic installations. Our data includes measurements performed at different dilution levels using both filter sampling and on-line particle measurement devices.

Our results suggest that only a small fraction of the organic gaseous carbon emissions is the main source of SOA for these appliances. This fact will be exemplified by measurements performed on appliances equipped with a combination of a flue gas cooling system and an electrostatic precipitator for filtering raw gas emissions. This aftertreatment system influences the gas-to-particle phase partitioning and reduces the potential for SOA production to levels which are only achievable by larger installations with a very efficient combustion. The reduction of non-methane hydrocarbons due to the after treatment system is however only marginal.

Finally, we will show results from positive matrix factorization (PMF) analysis of on-line data collected by means of an Aerodyne Aerosol Mass Spectrometer (AMS). The high time resolution of our system allows for a clear picture of the SOA production potential throughout the combustion cycle and a better understanding of the processes that contribute the most to the formation of SOA.

This research was supported by the Swiss Federal Office for Energy (SFOE), the Swiss Federal Office for the Environment (FOEN) and the OPTIWARES project of the Competence Center Energy and Mobility (CCEM) from the ETH Zurich.

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Kireeva Elena / University Moscow

Size – segregated organic/ inorganic composition of particulate emissions in periods of extensive biomass burning.

Aerosols significantly impact the regional environment, including climate change, specifically in periods of extensive biomass burning (BB). Emissions and properties of BB aerosols are highly source-dependent, depending on burning practice, combustion phase (open flaming vs. smoldering), and type of biomass. Quantification of BB emissions is in the focus of current research and abatement strategies, especially given that the impacts of BB on regional air quality in highly populated areas are remaining rather uncertain.

This work reports the measurements during the dry seasons of 2013 in Son La Province, northwest Vietnam, and of 2015 in Ba Vi Province , Central Vietnam. We focus on physico-chemical properties of aerosols, affected by biomass burning activities from agricultural and domestic combustion sources. The comparative analysis of particle organic/inorganic composition is carried out by Fourier Transform IR (FTIR) spectroscopy. The characterization of near-source emissions from traditional burning activities (on-field burning and domestic cooking) as well as traffic emission is specifically conducted in order to identify the major functional groups in ambient smoke.

Analysis of FTIR spectra of particles in on-field and cooking emissions demonstrate the prominent absorption bands are related to aliphatic C-C-H, acid carbonyl C(O)OH, non-acid carbonyl C=O and carboxylate carbonyl RC(O)O groups. Asymmetric N–O stretches in nitro compounds as well as hydroxyl C-OH groups can be noted as specific features of on-field smoldering emission. Cooking emission is found additionally rich by ammonium NH_4^{2-}, aromatic C=C-H, and Ar–NO_2. FTIR spectra of on-road emission demonstrates the spectral absorption by aliphatic C-C-H in alkanes, and aromatic C=C as the functional markers of gasoline exhaust. The prominent absorption bands of acid and non-acid carbonyls, carboxylates, and aliphatic carbon during the whole BB period are similar to those in the on-field and cooking emissions. The band of ammonium is prominent in ambient aerosols. The bands of C-N-H in amines on days of low smoke can be assigned to biogenic functional groups, and were consequently absent in high smoke periods. The absorption bands of sulfates are identified in coarse particles.

The relative concentrations of NH_4^+, aliphatic C-C-H, carbonyl C=O and C(O)O, carboxylate RC(O)O, CO_3^-, and SO_4^{2-} in size-segregated ambient aerosols (PM 2.5, PM 1-2.5, PM 2.5-10) are classified at low, moderate, and high smoke levels, with respect to the evolution of aerosol chemistry from the BB emission sources into the ambient atmosphere. In $PM_{2.5}$ all organic functionalities increase throughout the study period. Conversely, the relative concentrations of ammonium are not well correlated with the smoke intensity, indicating regional source influence other than from BB. Relative concentrations of carbonates are increasing from low to high smoke, and hence, showing the impact of re-suspended soil particles during intensive agricultural fires on the composition of coarse ambient aerosols.

Finally, this work allows the decreasing the uncertainties in chemical identity of combustion particulate emissions in periods of extensive biomass burning and quantification of their environmental effects.

This work was financially supported by VAST – RFBR project 15-5554020 and VAST. HTQT. NGA. 04/15-16.

Kittelson David / University of Minnesota

Semi-volatile Particle Emissions from Engines Operating in Low Temperature Combustion Modes

In the late 1990's the USEPA considered the regulation of particle number emissions from engines. However, a number of investigations of possible measurement techniques revealed that although instruments suitable for measuring particle number concentrations were available, systems sampling and diluting exhaust in a representative manner were not. Relatively modest changes in dilution conditions could alter semi-volatile particle number concentrations by more than an order of magnitude and often most of the number emissions were semi-volatile. This led to suspension of consideration of regulation of total particle number emissions in the US at that time.
Europe approached the problem of number emissions in a more practical manner and set out to regulate what could be measured in a relatively straightforward manner. It was found that unlike semi-volatile particle number measurements, solid particle number measurements were insensitive to dilution conditions. The Particle Measurement Program (PMP) developed standard procedures for measuring solid particle number emissions focusing on solid particles larger than 23 nm diameter. The PMP method is now used to regulate emissions from both Diesel and spark ignition vehicles in Europe. Solid particle emission standards are also being developed for aircraft based on a modified version of the PMP method that measures solid particles larger than 10 nm. These standards are to be applied worldwide and are expected to be in place by 2020.
However, there is lingering concern that semi-volatile particles, excluded from the current number standards, may be associated with health hazards. Furthermore, many fuel and engine technologies that decrease emissions of solid particles, increase emissions of semi-volatile particles. Some examples of this are engines fueled with non-sooting or nearly non-sooting fuels like hydrogen, DME, and natural gas and engines operating in low temperature combustion modes including homogeneous charge compression ignition (HCCI), partially premixed compression ignition (PCCI) and reaction controlled compression ignition (RCCI). Recent work on solid and semi-volatile emissions from diesel engines operating in HCCI, PCCI, and HCCI modes will be described. Scanning mobility particle sizer (SMPS) measurements made with and without a catalytic stripper have been used to determine size fractionated concentrations of total, solid, and semi-volatile particles. Measurements were made using different dilution strategies. The sensitivity of these measurements to dilution conditions will be discussed.

Køcks Morten / Danish Technological Institute

DPF+SCR retrofit of Construction Machines: Real-time characterization of emission reduction and optimization during realistic operating conditions

Background

Construction machines are responsible for a significant part of the total particle and NO_x pollution in urban areas. The engines used in construction machines are regulated by Stage standards, which are less stringent than Euro standards with respect to NO_x and PM. An important issue relating to construction machines is also that the construction site workers are close to the machines and hence continuously exposed to the emissions.

The goals of this work are to develop suitable and effective retrofit technology for selected construction machinery as well as to develop a method for online emission characterization during realistic operating conditions. Shown here is effect of DPF+SCR retrofit and real-time emission data from a Deutz TCD 2011 45-kW Stage IIIA diesel engine powering an VÖGELE Super 800 asphalt paver.

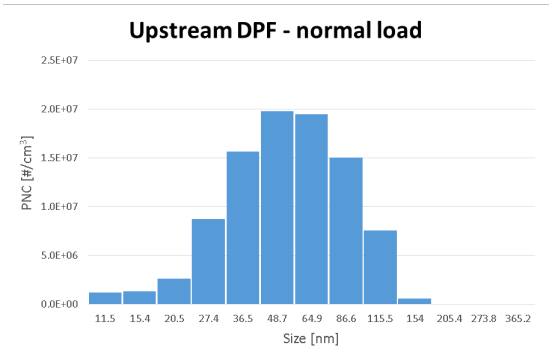
Experimental

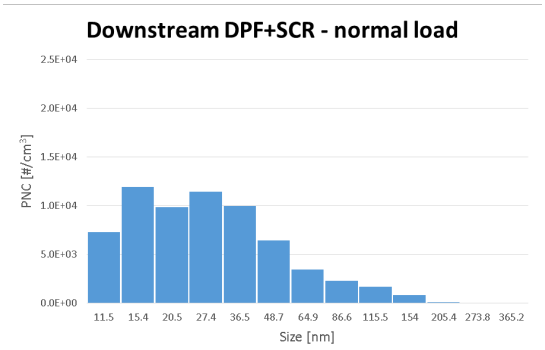
Measurements are carried out from a van driving right next to the machines on a test facility. The gas and particle sample stream is transferred from the exhaust system to instruments inside the van. Particle number and size are measured in the size interval 10-420 nm using a NanoScan SMPS connected after a rotating disc diluter (hot dilution) and a catalytic stripper for removing the semi-volatile particle fraction. Gas emissions (CO, CO_2, THC, NO, NO_2, NO_x, NH_3, and N_2O) are measured using Fourier-Transformed Infrared Spectroscopy (FTIR).

Results and conclusions

The asphalt paver was retrofitted with two different DPF+SCR solutions. The first system was oversized to ensure trouble-free engine operation. The second solution was optimized for the particular machine, and a down-scaled version of SCR and DPF was implemented. In addition, an ammonia slip catalyst was installed following SCR in order to minimize ammonia emission.

With respect to particle emission, the two tested DPF+SCR solutions reduce PN by more than 99.9 % in the size interval 23-420 nm, with 23 nm being the lower cut-off in PMP. Data were averaged over several measurement cycles during warm engine conditions and measured during realistic and normal operating conditions. In addition, the average measured PN concentration downstream DPF+SCR is about a factor of 5-10 below the PN reference value being suggested by the Swiss Federal Office for the Environment ($2.5x10^5$ particles/cm^3), for passing a DPF test. Interestingly, a significant amount of the solid particles measured downstream DPF+SCR have a size below 23 nm, as seen below.





Development and implementation of DPF and SCR technology for the asphalt paver was successfully carried out as well as the measurement approach and setup with a van driving next to the construction machines. Real-time emission data were acquired with accurate instruments during realistic operating conditions. With the downscaled and optimized DPF+SCR retrofit solution, the asphalt paver was shown to be compliant with Stage IV limits on PN, NOx, THC and CO during the described measurement conditions (not standardized test according to ISO 8178).

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

Kumazawa Shinji / NGK SPARK PLUG Japan

PM/PN measurement Repeatability of Compact Multi Gas Measurement System

<Background>
Recently the air pollution has been more serious in the world and the emission regulation for vehicles is getting quite severe. In Europe, deviation of the vehicle emission level between lab-certification base and real driving base is a subject of discussion. For the issue, EU is considering to introduce RDE (Real Driving Emission) regulation using PEMS (Portable Emission Measurement System). But the current
PEMS has some issues in term of portability, complexity and etc.

<Investigation method>
We develop real portable and easy handling multi gas measurement system utilizing direct insertion type exhaust OBD (On Board Diagnosis) sensors technologies.
These technologies are able to measure in real time the particle matter and nitrogen oxide in the exhaust gas. (Hereafter, referred to as NTK PM sensor and NTK NOx sensor)
We have compared NTK PM sensor and NOx sensor with the reference apparatus under FTP (Federal Test Procedure) mode in order to check the repeatability.

<Result>
NTK PM sensor's principle is a diffusion charging method then it can measure PM and PN. Fig.1 and Fig.2 show real time measurement waveforms of NTK PM sensor and PM and PN references apparatuses (AVL ESS and TSI EEPS). Real time PM and PN waveforms of NTK PM sensor show almost the same behavior with references apparatuses. (Considering difference of each exhaust gas traveling time, waveform is adjusted to lap each data.) We test 3 times and good repeatability data were observed.

Fig.3 shows the real time measurement of NTK NOx sensor and the reference apparatus (HORIBA MEXA-ONE). Real time NOx output is almost overlapped with the reference apparatus and its repeatability is observed under multiple tests.

<Conclusion>
1. Direct insertion type exhaust OBD (On Board Diagnosis) sensors technologies can measure amount of PM, PN and NOx in the exhaust gas in real time.
2. Good repeatability is confirmed by comparison with reference apparatuses (MSS, EEPS and MEXA-ONE).

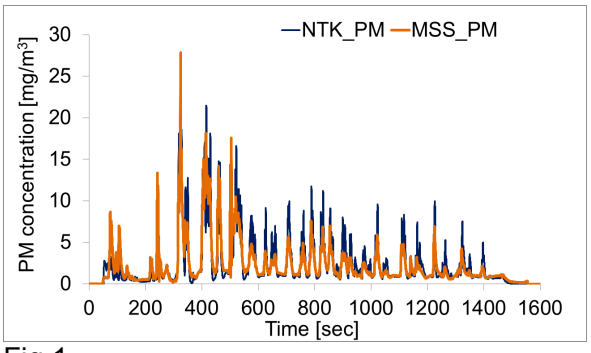


Fig.1

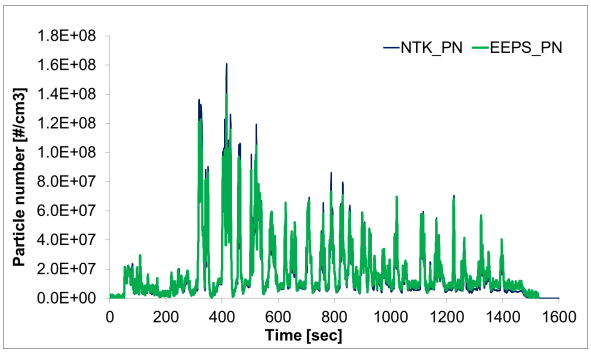


Fig.2

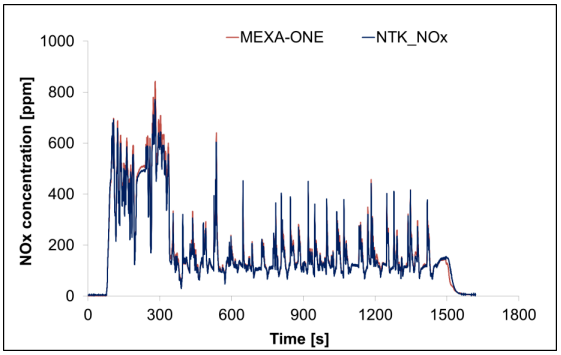

MEXA-ONE
NTK_NOx
NOx concentration [ppm]
1000
800
600
400
200
0
0
300
600
900
1200
1500
1800
Time [s]

Fig.3

Kuntze Arne / Physikalisch-technische Bundesanstalt

Metrology for portable emissions measurement systems (PEMS)

The legal requirements for light-duty vehicles shift towards a more stringent and accurate determination of engine exhaust emissions (for diesel as well as gasoline) measured during more realistic operation conditions, i.e. during real driving emission scenarios. This development is expected to accelerate in particular after the recent findings on vehicle emission manipulations. While in-lab procedures still remain to be the core testing scenario, measurements will expand towards on-road tests. Recently portable emissions measurement systems for RDE tests have started to become commercial available. However, they often employ new instrument formats, which – compared to the typical lab instruments – have to be strongly modified to meet the weight, size and power requirements for on board-use in vehicles during field tests. Further, the new instruments are based on different principles like diffusion charging instead of the more common condensation particle counters and thus are to be checked for equivalency with in-laboratory instruments. Therefore, it is necessary to ensure comparability of the results between the “mobile” and the “stationary” measurement principles. So far, the characteristics of the new instruments have not been tested under metrological conditions, traceability to SI-units is thus not ensured. However, there is a strong need to link the performance of PEMS to a metrological scale in order to establish metrological comparability like traceable measurements for condensation particle counters regarding size and number concentration. For those parameters an independent calibration is needed, especially for such PEMS-devices. Most critical will be NOx emission from diesel engines. Since 2010 various member states do not meet the emission ceilings for NOx emissions [1]. The road transport sector bears most of the blame for the anticipated exceedances, according to the EEA, contributing to almost 50 % of total EU-28 NOx emissions in 2013 [2]. This is not surprising, as this sector shows strong growth, while the vehicle emission standards have not always delivered the anticipated level of NOx reductions [3]. The poster will deal with the named issues and will show open spots to be considered to fulfil legal requirements, as well as address needs of stakeholders like vehicle- and device manufactures and monitoring authorities.

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NEC Directive status report 2014 Reporting by Member States under Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001 on national emission ceilings for certain atmospheric pollutants
[2] Air Quality in Europe – 2015 report, doi: 10.2800/62459
[3] http://www.eea.europa.eu/data-and-maps/indicators/eea-32-nitrogen-oxides-nox-emissions- 1/assessment.2010-08-19.0140149032-3, 04.03.2016, 11:40

Kureti Sven / University of Freiberg

Soot Oxidation on Manganese Oxide Catalysts in Gasoline Exhaust

Introduction

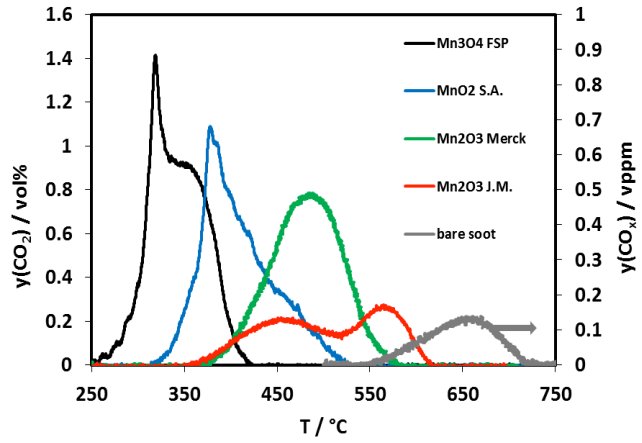
Gasoline engines with direct fuel injection (DI) reveal high efficiency associated with reduced CO_2 emission. However, an issue is the output of soot particles, which are carcinogenic and contribute to greenhouse effect. Due to strengthening of emission limits, e.g. Euro-VI, the output of soot from DI gasoline engines comes more and more under pressure similar to diesel engines. Thus, gasoline particulate filters (GPF) with passive regeneration are considered. In this context, our paper addresses the development of MnO_x catalysts for oxidation of soot by O_2 in GPF systems. Manganese oxides were reported to be active for oxidation of hydrocarbons and soot in excess of oxygen.

Experimental

A systematic series of manganese oxides were synthesized and characterised by powder X-ray diffraction, N_2 physisorption, scanning electron microscopy, temperature programmed reduction by H_2 and temperature programmed desorption of NH_3. Catalyst screening was performed by temperature programmed oxidation (TPO) using tight and loose contact powder mixtures of catalyst and soot (Printex U). Additionally, for more practical assessment, the best catalyst was coated onto a laboratory GPF followed by deposition of C_3H_6-soot and catalytic test.
For mechanistic investigation of oxygen transfer from gas-phase to catalyst and soot, isotopic TPO studies with $^{18}O_2$ were made with powder mixtures.

Results and discussion

The TPO tests demonstrated Mn_3O_4 prepared by flame spray pyrolysis (FSP) as best catalyst providing soot combustion already at 300°C; exemplary TPO profiles are shown in Fig. 1(a). Additionally, clear enhancement of soot oxidation was also observed when performing tests with the laboratory-scaled filter coated by the FSP catalyst. Moreover, the Mn_3O_4 catalyst revealed high thermal stability after hydrothermal exposure at 750°C and thermal treatment at 1050°C.
The correlation of physical-chemical characteristics with soot oxidation kinetics showed that the number of surface oxygen vacancies determines the performance of the catalysts (Fig 1b). Furthermore, the isotopic TPO studies suggested that oxygen is transferred from the surface and bulk of the Mn_3O_4 catalyst to the soot by physical contact points. A strong contribution of bulk oxygen (ca. 60%) occurred. The role of gas-phase O_2 was found to refill oxygen vacancies of catalyst [1].



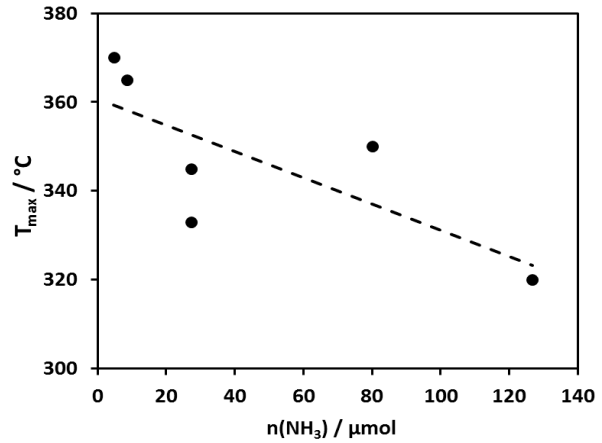


Figure 1. (a) TPO of tight contact mixtures of soot and Mn_3O_4 (FSP) (1% O_2, 2% H_2O, N_2 balance). (b) Correlation of temperature of peak CO_2 formation upon TPO and number of oxygen vacancies of MnO_x catalysts.

Conclusion

Bare MnO_x catalysts were tested for soot oxidation in GPF systems, whereas Mn_3O_4 (FSP) showed outstanding activity highly relevant for practice. This catalyst only slightly changed its performance after hydrothermal and thermal exposure. The correlation of physical-chemical properties and soot oxidation activity indicated that the surface oxygen vacancies are crucial for catalytic efficiency. This coincides with isotopic studies suggesting that the supply of oxygen occurs from gas-phase and catalyst bulk via catalyst surface to contact points of soot. Moreover, tests of laboratory-scaled filter coated with Mn_3O_4 reveal activity below 300°C indicating remarkable potential for soot conversion in gasoline exhaust.

Literature

[1] S. Waglöhner, J. N. Baer, S. Kureti, Appl. Catal. B 147 (2014) 1000

Acknowledgment

Financial support by Fachagentur Nachwachsende Rohstoffe (FNR) under the project BiOtto is thankfully acknowledged.

Langenkamp Peter N. / University of Groningen, The Netherlands

Silica formation in flames with siloxane admixture: effects of admixture concentration, flame temperature and equivalence ratio

Biogases can play an important role in a transition away from fossil fuels, but often contain impurities such as siloxanes that complicate their usage. SiO_2 molecules generated in the combustion of siloxanes coalesce together into particles which subsequently form even larger aggregates and deposit on internal parts of combustion equipment. This has significant implications on the equipment's lifespan. We used (non-invasive) angle dependent light scattering to investigate aggregate growth in one-dimensional premixed CH_4/hexamethyldisoloxane (L2)/air flames at various siloxane concentrations, flame temperatures and equivalence ratios, using Guinier analysis to interpret the experimental data.

L2 was added to burner stabilized premixed methane/air flames through a bubbler system, in concentrations ranging from 150 to 800 ppm. Heat losses from the flame to the burner allow for variation of the flame temperature independent on the equivalence ratio, by changing the exit velocity of the gas mixture. A 532 nm cw laser beam is directed through the flames. Light scattered by particles in the flame is detected simultaneously by photomultipliers placed at four distinct angles. Calibration of the measured signals was performed using Rayleigh scattering from SF_6.

A sublinear dependence of the aggregate radii of gyration R_g of generated silica particles on residence time has been observed in all flames, with radii of gyration R_g in the range of 10 to 120 nm. Measurements for a range of flame temperatures, at fixed equivalence ratio, revealed a non-monotonic dependence of R_g on flame temperature: R_g increases with temperature up to around 2000 K, but decreases thereafter. Remarkably, from measurements at different equivalence ratios, a lean flame environment appears to foster aggregate growth compared to rich and stoichiometric flames, in which growth is very similar. When fixing the initial conditions at the residence time corresponding to the first measurement point, a simple model describing particle evolution as a result of collisional growth and sintering predicts the functional dependence of the growth of particle radii well.

Lee Seokhwan / Korea Institute of Machinery and Materials

Particulate Emissions Emitted from DI Diesel Engine Operated with Wood Pyrolysis Oil

The vast storage of biomass available in the worldwide has the potential to displace significant amounts of fuel that is currently derived from petroleum sources. Fast pyrolysis of biomass is one of possible paths by which we can convert biomass to higher value products. The wood pyrolysis oil (WPO) has been regarded as an alternative fuel for petroleum fuels to be used in diesel engines. Because WPO is an oxygenated fuel which contains more than 40% of oxygen, WPO can significantly reduce the PM generation in a diesel engine. However, the use of WPO in diesel engines requires modifications due to low energy density, high water contents, high acidity, and high viscosity of the WPO.

There are several methods to apply WPO in diesel engines. At first, the most widely used approaches to adopt WPO to diesel engine without engine modifications are blending or emulsification of WPO with diesel and biodiesel (BD). WPO is immiscible with diesel and biodiesel, hence proper surfactants or co-solvents are needed for emulsification or blending.

WPO is easily mixed with alcohol fuels such as ethanol and butanol. Early mixing with alcohol fuels has an added benefit of significantly improving the storage and handling properties of WPO. Therefore, blending WPO with alcohol fuel is another viable method to apply WPO in diesel engines. However, WPO-alcohol blended fuel does not produce the self-ignition due to the lower cetane number of WPO and alcohol fuels; hence additional cetane enhancements should be added in the blended fuel. In this study, we would like to use WPO through the mixing with n-butanol and cetane enhancements.

Lastly, dual-injection strategy was adopted. In this strategy, a pilot fuel with a high cetane number such as diesel or bio-diesel was injected as first action to develop a flame in the combustion chamber with which the main WPO-ethanol blended fuel was stably combusted.

In this study, WPO was applied in a single-cylinder DI diesel engine using the above mentioned strategies. PM mass and particle number (PN) concentration were measured to evaluate the effect of oxygen contents in WPO on the PM formation. All the experimental results were compared to the results of pure diesel under the same experimental conditions. The experimental results showed that PM mass emissions were significantly decreased and PN concentrations were increased due to the high oxygen content of WPO.

Lehtoranta Kati / VTT Finland

Particle emissions from a natural gas engine with and without a catalyst

Introduction

The usage of natural gas in energy production is increasing. When compared to use of liquid fossil fuels, natural gas engines have lower CO_2 emissions and, in addition, typically smaller particulate matter (PM, mass) and NO_x emissions. The particle number emissions of natural gas engines, however, can be still at significant level, and the emissions of gaseous compounds like CO and HC are typically higher from natural gas engines compared to liquid diesel fuel engines. To comply with tightening emission limits for these gaseous compounds, after-treatment systems are expected to be increasingly utilized with the natural gas engines. The utilized after-treatment system can have an effect on other emissions components as well. In this study we focus on particle emission of natural gas engine, especially on the effects of catalyst system on the exhaust nanoparticle formation.

Experimental

A newly developed research facility (Murtonen et al. 2016) including a passenger car engine modified to run with natural gas was utilized in present study. In addition, a catalyst system consisting of a combination of a selective catalytic reduction (SCR) and an oxidation catalyst was utilized. Emission measurements were made upstream and downstream of the catalyst system. Particle mass, number, size distribution and composition were studied utilizing a diluting sampling. Engine Exhaust Particle Sizer (EEPS), Scanning Mobility Particle Sizer (nano-SMPS), Electrical Low Pressure Impactor (ELPI) and Particle Size Magnifier (PSM) combined with Condensation Particle Counter (CPC) were utilized for size distribution and number measurements, chemical composition was measured using Aerosol Mass Spectrometer (AMS) and total mass with filter sampling (ISO 8178).

Results and discussion

Particles emitted from the natural gas engine were found to be small, even smaller than 5nm in diameter when the engine is not equipped with any catalyst system (Alanen et al. 2015). Both the non-volatile and volatile compounds were found to exist in particles (Figure 1). Downstream of the catalyst the particle formation was observed to be significantly affected by the exhaust temperature. At the lowest temperature studied the particle numbers downstream of the catalyst were lower compared to engine out levels, but at high catalyst temperatures the particle numbers were remarkably higher and mean particle size was significantly larger downstream of the catalyst (Figure 1). The PM mass results and the AMS results indicate that the catalyst clearly reduces organic matter, while at higher temperatures it increases the sulphate and ammonium levels (Lehtoranta et al. 2016).

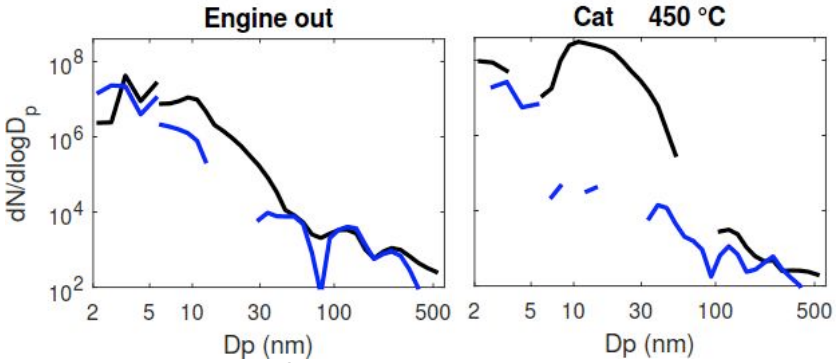


Figure 1. Examples of particle size distributions measured using PSM+CPC and EEPS. Black lines indicate size distributions of all particles, while blue lines indicate non-volatile par-

ticle size distributions. Partial exhaust sampling with cooling dilution was used, nonvolatile fraction was measured using a thermodenuder upstream aerosol instruments.

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Li Zepeng / Abdullah University, Jedda

Effect of Dimethyl Ether Mixing on Soot Size Distribution in Premixed Ethylene Flame

As a byproduct of incomplete combustion, soot attracts increasing attention as large amounts of researches exposed the serious health and environmental effects generated from soot particles. Soot emission reduction requires comprehensive master of the mechanism for polycyclic aromatic hydrocarbons and soot formation and aging processes, therefore advanced experimental techniques and numerical simulations have been developed to investigate soot formation and aging processes.

In order to investigate the effect of dimethyl ether (DME) mixing on soot particle size distribution functions (PSDFs), DME was mixed in premixed ethylene/oxygen/argon flat flames at the equivalence ratio of 2.0 with mixing ratio range from 0% to 30% of the total carbon fed. Two series of atmospheric pressure flames were tested in which cold gas velocity was varied to obtain different flame temperatures.

The evolution of PSDFs along the centerline of the flame was determined by burner stabilized stagnation probe and scanning mobility particle sizer (SMPS) technique described in [1], yielding the PSDFs for various separation distances above burner surface. Meanwhile, the flame temperature profiles were carefully measured by thermocouple and the comparison to premixed laminar burner-stabilized stagnation flame simulations was satisfactory. Then light extinction technique was applied to quantify the effect of DME on soot volume fraction. Additionally, to understand the chemical role of DME mixing in soot properties, characterisation measurements were conducted on soot samples using thermo-gravimetric analysis and elemental analysis.

Results of the evolution of PSDFs and soot volume fraction showed that DME mixture with ethylene fuel could reduce soot yield significantly (figure 1). The addition of DME led to the decrease of both soot nucleation rate and particle mass growth rate. To explain the possible mechanism for the experimental results, numerical simulations were performed to analyze the concentrations of several crucial species in soot formation. Although DME addition resulted in the slight increase of methyl radicals from pyrolysis, the drop of acetylene and propargyl radicals inhibited the production of polyaromatic hydrocarbons, hence decreased soot formation. Furthermore, adding DME gave rise to the increase of the flame temperatures, which also accounted for the reduction of soot formation. Additionally, soot samples from flames with higher DME mixing ratio showed lower C/O, C/H ratios and better oxidizability.

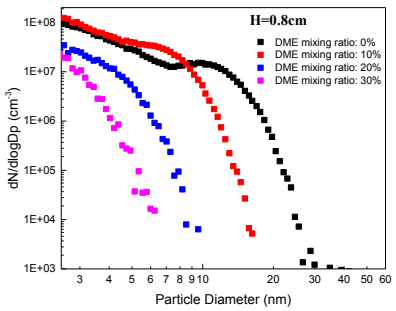


Figure 1: Comparison of measured PSDFs for flames with different DME mixing ratio at the separation distance between burner surface and stagnation plate of 0.8cm

Lindner Gert / Physikalisch-Technische Bundesanstalt

An accompanying CFD-study on partial flow sampling from a soot aerosol dilution setup

At the national metrological institute of Germany (PTB) a new preparative soot aerosol standard is currently developed. One goal of this development is e.g. to establish an independent calibration service for soot particle number concentration measurements in engine exhaust emissions following the PMP recommendation and the new ISO standard 27891 [1]. The main parts of the calibration infrastructure encompass a propane diffusion flame-based soot generator (mini-CAST) in combination with an aerosol dilution and mixing system. The current goal of this development is to further stabilize the soot mass output and the aerosol parameters of the generator and to optimize the sampling of an aerosol flow from the generator. Hence, in order to optimize the spatial aerosol distribution inside the soot generator, to ensure a stable and spatially homogeneous mixing and dilution configuration, and to allow a representative sampling from the aerosol flow inside the soot standard, accompanying computational fluid dynamics (CFD) studies were performed to generate an inside view of the gas-flow-soot-aerosol interaction process, in particular around the sampling probe tube [2]. The spatial soot aerosol distribution in the conditioning and testing section of the flow channel is affected by the turbulence of the carrier fluid. Besides, the mean flow characteristics of field variables like mass fraction for the amount of soot in the surrounding gas flow was modelled by an Euler-Lagrange approach to trace the particle transport (see Figure 1). Simulative particle tracking techniques are used to display the turbulence induced aerosol flow properties such as re-circulation zones inside the generator. At this time, we modelled the drag forces and the turbulent dispersion onto the particle collective. A hyper-kinetic flow regime is used to describe the particle sampling from the main flow inside the generator into the partial flow which is extracted by the sampling pipe (L-shaped type). To estimate the amount of soot particles which are trapped by the partial probe section new performance parameters are introduced, like the so-called “aspiration efficiency”.
The poster will deal with results of the simulations which are to be compared to measurements done with an ultrafine differential mobility particle sizer (3 to 240 nm) to characterize the influence of the turbulent mixing parameters of the CFD model at one selected particle size distribution around 55 nm.
At first, it could be shown that the mean field variables like velocity magnitude are in the expected range of different locations. Then the mixing process can be observed on different downstream positions of the dilution system. Further, we show that an increased negative pressure on sample outlet leads to an increased aspiration efficiency.

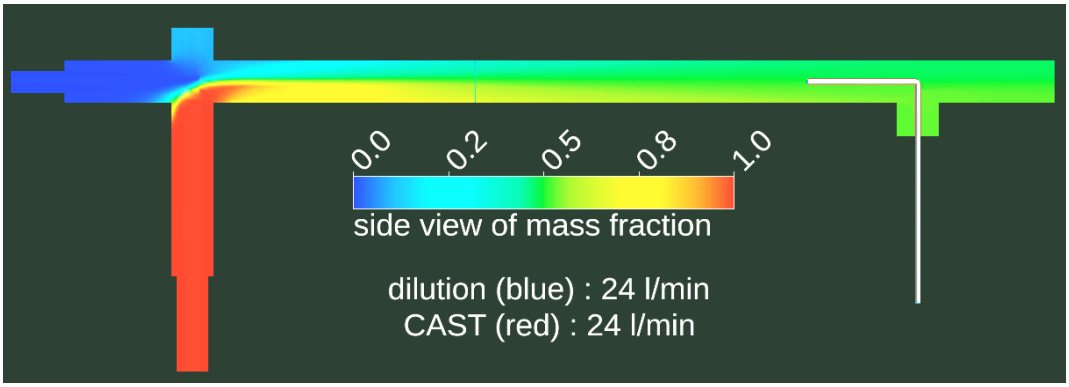


Figure 3: Contour plot for the simulated mass fraction of dilution air (blue) and soot aerosols (red) based on spatially-dependent mixing of gas as carrier fluid. The flow direction is from left to right side in the main pipe. A L-shaped sampling pipe (white tube) is inserted in the aerosol flow to simulate the behaviour of the sampling line

With future measurements, it should be possible to compare the particle number size distribution injected at the inlet to those which are collected on the sample outlet (white L-shaped sampling pipe).

[1] ISO 27891:2015 Aerosol particle number concentration - Calibration of condensation particle counters
[2] G. Lindner, S. Schmelter, R. Model, A. Nowak, V. Ebert, and M. Bär. A computational fluid dynamics study on the gas mixing capabilities of a multiple inlet system. *ASME. J. Fluids Eng*, **138**:031302–031302–9, 2015.

Löschau Gunter/Saxon State Office for Environment, Agriculture and Geology, Dresden

Assessment of the effectiveness of the low emission zone Leipzig by measurements of soot and the ultrafine particle number concentration

A low emission zone aims vehicles with high particulate engine emissions in areas. The engine emissions of diesel and gasoline injection vehicles are believed to be toxic and carcinogenic. Diesel vehicles without particle filters emit ultrafine and fine particles, which consist largely of soot and carry other pollutants. The ultrafine diesel particles contribute to PM10 mass concentration only a very little and the control of the effectiveness becomes very uncertain. Therefore a joint scientific monitoring program has been realized by the Saxon State Office for Environment, Agriculture and Geology and the Leibniz Institute for Tropospheric Research to accompany and evaluate the introduction of the low emission zone in Leipzig by measurements.
The low emission zone in Leipzig was directly introduced with the green bagde in 2011. It comprises 62 % of the urban area. The announcement and enforcement of the low emission zone caused an accelerated modernization of the vehicle fleet in the city. The most modern car fleet of Saxony exists Leipzig presently.
Figure 1 shows the weekly variation of the ultrafine particle number concentration, which corresponds to similar traffic volumes. The weekly variation of the soot particle mass concentration is basically identical. The concentration decreased in 2014 to half compared with those of 2010 during daytime. The assessment of the effectiveness of the low emission zone, the increment of the particle concentration of the local traffic was determined by the so called Lenschow approach.
After four years Low Emission Zone, the soot mass concentration and the ultrafine particle number concentration were reduced by 47 and by 56%, respectively. This significant reduction was achieved due to the introduction of diesel particle filters pushed by more stringent European emission standards. However, the most modern fleet of Saxony brought no improvement for the NO_2 concentration in the city. The low emission zone in Leipzig led to an accelerated modernization of the vehicle fleet in Leipzig and to a reduction of highly toxic composition in particulate matter.

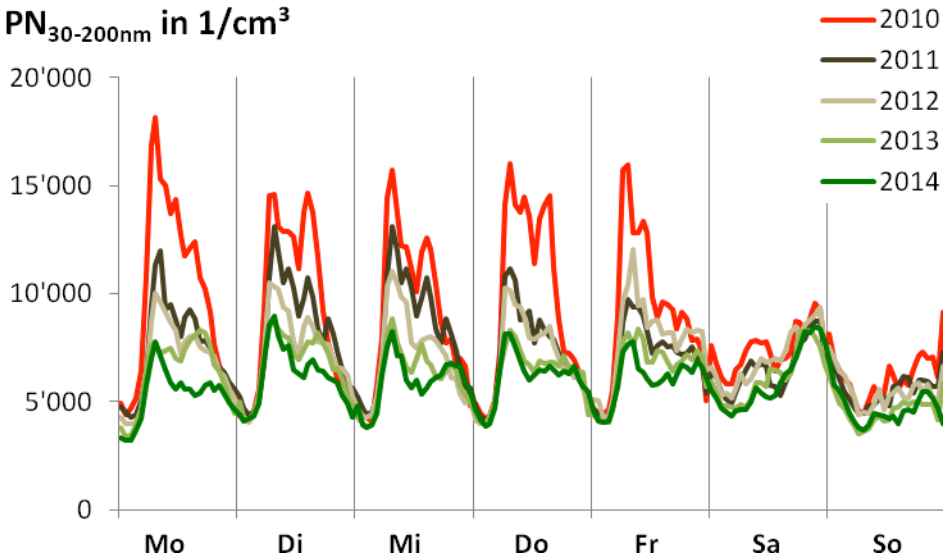


Figure 1: Weekly variation of the ultrafine particle number concentration (30 bis 200 nm) at the a roadside in the city of Leipzig before the implementation of low emission zone in 2010 and years later

Lüönd Felix / METAS Switzerland

A new, traceable METAS calibration service for particle counters

Accurate measurement of the aerosol particle number concentration is becoming increasingly important in many areas such as ambient air monitoring and has been recently introduced in vehicle emission legislation. Number concentration measurements are also integrated in particle size distribution measurements, e.g. when using Mobility Particle Size Spectrometers (SMPS). The increasing importance of aerosol metrology and in particular of the metric of particle number concentration implicates the need for traceable calibration services for condensation particle counters (CPCs).

We have established a traceable calibration procedure for the determination of the efficiency curve of CPCs according to ISO 27891. The calibration of the CPC under test relies on the comparison with a Faraday-cup-aerosol-electrometer (FCAE) coupled to a flow meter. This method makes measurement of particle number concentration traceable to the units of electric current and volumetric flow. As primary standards for both quantities are established at METAS, the combination of a FCAE with a flow meter can serve as a METAS primary standard for particle number concentration.

The calibration is carried out with a size-selected and thermally treated combustion aerosol generated by a CAST-generator in the size range from 10 nm to 200 nm. The linearity of the CPC under test (dependency of the counting efficiency on the particle number concentration) can be determined using concentrations in the range from 1'000 cm^{-3} to 20'000 cm^{-3}.

Monodispersity of the size-selected aerosol is a priori limited by the presence of larger particles carrying multiple charges. The size resolved measurement of counting efficiency therefore requires correction of the measured values with respect to multiply charged particles. We present the detailed procedure applied for multiple charge correction compliant with ISO 27891 (Calibration of CPC's).
Examples of calibration results are presented along with a full uncertainty budget. With the present method, relative uncertainties in the counting efficiency below 5% can be reached throughout the applied size range. Figure 1 shows examples of cut-off curves obtained during calibration of various CPCs.

Our calibration service based on the present method is internationally recognised by virtue of the Calibration and Measurement Capability (CMC 235-2) for charge concentration of airborne particles, included in the Mutual Recognition Arrangement (MRA) of the Committee for Weights and Measures.

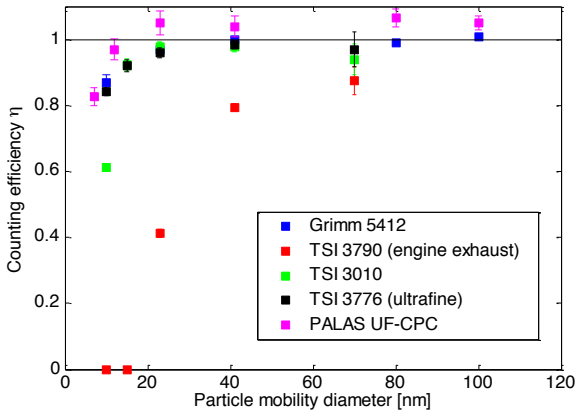


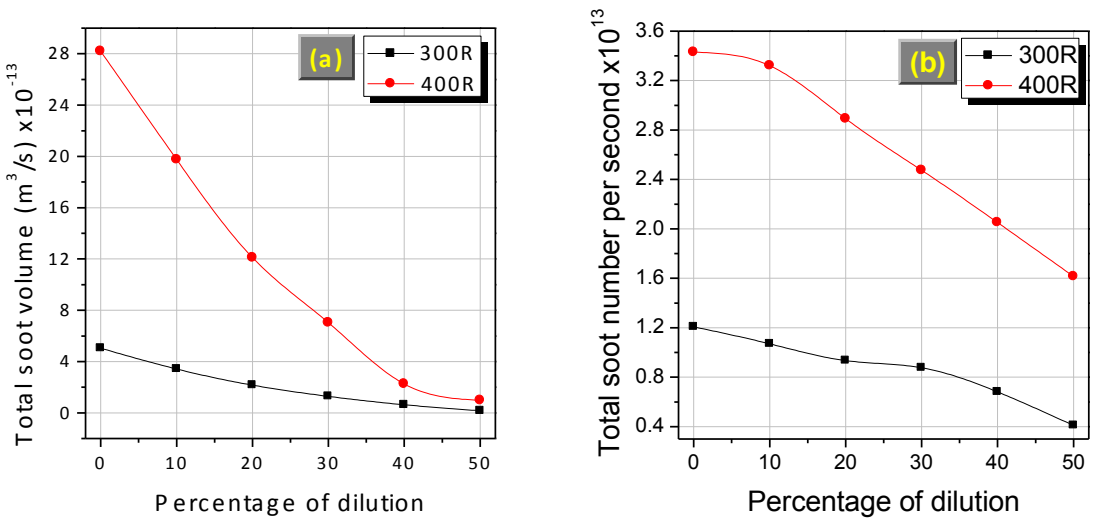
Figure 4: Example of CPC cut-off curves achieved by calibration against the new METAS reference for particle number concentration.

Mandal Bijan Kumar / Mechanical Engineering, Indian Institute of Engineering Science and Technology

Numerical Study on the Combined Effect of Fuel Dilution and Air Preheating on Soot Formation in Diffusion Flame

Soot is a carcigeneous nanoparticle formed during combustion of fuels in diffusion mode. Dilution of the fuel with chemically inert gases like nitrogen, argon and helium is one of the possible methods for soot reduction. On the other hand, air preheating results in the increase of soot formation. The influence of nitrogen addition to the fuel and preheating of air on soot formation in an axisymmetric coflow laminar methane/air diffusion flame has been numerically investigated. The physical model of the burner consists of two concentric thin walled tubes where fuel stream enters through the inner tube at a temperature of 300 K and the non-preheated (300 K) or preheated (400 K) air through the annular space as oxidizer. The numerical model is based on the solution of conservation equations of overall mass, different species concentrations, axial momentum, radial momentum and energy for axisymetric geometry. An optically thin radiation model has been considered to take into account the effect of radiation from the flame. A semi-empirical two-equation soot model, based on the conservations of soot mass concentration and soot number density, has also been solved along with the other conservation equations with appropriate boundary conditions using explicit finite difference computing technique. The details of the model can be obtained elsewhere [1]. Nitrogen is added to the fuel in such a way so that it becomes a certain percentage (0%, 10%, 20%, 30%, 40%, and 50%) of total mixture. The prediction shows that flame height decreases with the addition of nitrogen to the fuel for both non-preheated and preheated air, but the flame height is always less with preheated air for all levels of dilution. Temperature of the flame is reduced with dilution of non-preheated and preheated air. Soot volume fraction increases when preheated air is used. On the other hand, soot is considerably reduced as the concentration of nitrogen is increased in the fuel stream with non-preheated as well as preheated air.

The variations of total soot and soot particle number with fuel dilution have been shown in Fig. 1(a) and Fig. 1(b) respectively. The total soot and soot particle number both decrease with the increase of fuel dilution for both the cases of non-preheated and preheated air.



From Fig. 1 (a), it can be noted that the total soot formation using preheated air and fuel (methane) diluted by the addition of 35% nitrogen to it will be approximately same as to the case of non-preheated air with no dilution of fuel. Hence it may be a good option to use preheated air as source of oxidizer for combustion and around 30% diluted fuel to get the benefit of preheated air along with a tolerable soot limit.

References:

1. B. K. Mandal, A. Sarkar, A. Datta, Transient development of flame and soot distribution in laminar diffusion flame with preheated air, J Engg Gas Turb Power. 131 (2009) 031501-9.

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Effect of biofuel additive on particle size distribution

The development of air transport contributes to the increase in the number of flight operations, resulting in the need to increase the number of aircraft. The result of the dynamic growth of air transport is increasing demand for fossil fuels, generating increased exhaust emissions. Emissions from air transport, adversely affect air quality, especially in the airports areas; it is also a cause of greenhouse effect. Current situation contributed to the exacerbation of the requirements for environmental performance of aviation powertrains. One way to meet the requirements for aviation powertrains in the field of environmental protection, is the introduction of alternative fuels intended for the supply of aircraft engines. The most common alternative fuels are particularly ethanol and esters of vegetable origin. Alternative fuels designed for use in air transport must meet strict criteria, including physicochemical properties directly affecting the combustion process, production costs, availability, and safety.

The aim of this study was to determine the size distribution of particles emitted by the jet engine GTM-120 fuelled with Jet A-1 and its blend with bioester FAME (Fatty Acid Methyl Esters) in a 1: 1 (B50). Determination of the size distribution of particulate matter depending on the fuel used made it possible to determine the effect of bioester on the emissivity of the jet engine. Measurements were carried out under laboratory conditions on a prepared test stand. Using an apparatus for measurement of particulate emissions from jet engine the particle size distributions were determined.

The result of biofuel use as an additive to jet fuel, was the change of size distribution of particles emitted by turbine engine in relation to distributions received during engine operation fueled with pure Jet-A1. Obtained results of the first part of the measurement range (values of thrust 10 N to 60 N) indicate on the increase of the diameters of the particulate matter in the case of the bioester use as additive to Jet A-1 in relation to size distribution of particles emitted by jet engine supplied with Jet A-1 without any additive compound. For the first three points of measurement (10-30 N) values of the characteristic diameter of determined size distributions of particles, turned out to be higher by 15% for the engine fueled with B50. Analyzing the measuring points for the thrust values of 70-120 N was found that bioester addition causes no effect on size distribution of emitted particles. In thrust values of 100-120 N no significant differences between particle size distribution obtained for both fuels were found and for maximum value of thrust (120 N) dimensional distributions were very similar. It has been found that increasing the thrust values of the engine, regardless of the type of fuel used, effects in reducing the diameter value of emitted particles.

Moisio Mikko / Dekati Finland

47 mm PM-Filter Holder with Real Time Particle Detection

Particle mass (PM) emissions from vehicles and other combustion sources are commonly measured by weighing the particles collected on a 47 mm filter. The method is laborious, it doesn't provide any real-time information on when the particles were emitted, and with current low-emitting vehicles its uncertainty and test-to-test variation is relatively high compared to other PM measurement methods. However, gravimetric method is still the basis of all PM mass emission regulations.

In order to improve gravimetric PM measurement method and to overcome some of its disadvantages, Dekati Ltd. has developed a new tool for gravimetric PM emission measurements. The system consists of a standard 47 mm gravimetric PM filter holder combined with an integrated miniature diffusion charger (DC) which provides second-by-second information on PM accumulation to a filter. The real-time detector is equipped with its own pump so that normal PM filter flow is unaffected and the system is battery-operated and fully automated minimizing the required operator work. The assembly is approximately the same size as a normal PM filter holder and it fits directly into all existing PM filter sampling systems, CVS or partial flow diluters, and tolerates 47 °C cabinet temperature.

In this presentation, we present the system construction and operation, its calibrations and test results from a series of GDI vehicle tests. We compare gravimetric and DC measurement sensitivities and show how the real-time signal can be used for gravimetric measurement quality control. We show challenges in comparing diffusion charger and gravimetric PM results and finally discuss other possible measurement applications like PEMS and power plant measurements.

Muñoz Maria / EMPA Switzerland

Comparison of PAH levels and mutagenicity of GDI- and a Diesel vehicle exhaust and impact of (bio)ethanol

Abbreviations: gasoline direct injection (GDI); polycyclicaromatic hydrocarbons (PAH); diesel particle filter (DPF); Worldwide Harmonized Light Vehicles Test Cycles (WLTC); constant volume sampler (CVS); High resolution gas chromatography-high resolution mass spectrometry (HRGC-HRMS).

Background:
GDI vehicles appear to be promising technology for reducing exhaust emissions and fuel consumption. However, several sources reported high emissions of particles exceeding the Euro 6 limit of $6x10^{11}$ particles/km. In addition, increased emissions of genotoxic pollutants (e.g. PAHs) are produced. It is known for PAHs that they can induce genotoxic responses inside cells causing mutations, which may lead to cancer. The WHO also classified several PAHs as carcinogenic, like benzo(a)pyrene, a group 1 carcinogen.

Methods:
Complete exhaust samples, including solid, condensed and gaseous fractions were collected from 5 different GDI vehicles (V1-V5) on a chassis dynamometer. Vehicles were driven following the WLTC under hot and cold start conditions. Vehicle 1 was also tested with two ethanol blends (E10 and E85). Diluted exhausts were sampled from a CVS tunnel. In addition, an Euro-5 diesel vehicle equipped with a filter was tested. Samples were processed following extraction and cleanup procedures and analyzed by HRGC-HRMS and concentrations of PAHs, alkyl-PAHs and nitro-PAHs were determined.
In order to compare the effects of the fuels relative to the mutagenicity, aliquots of the exhaust extracts (5%) under hot driving conditions of vehicle 1 (with gasoline, E10, E85) and the diesel vehicle were tested for mutagenicity using the bacterial Ames test with a commercial mutagenicity assay kit (Xenometrix, S. typhimurium, strains TA98 and TA100). The extracts were directly exposed to the bacteria for 1.5 h, dispersed bacteria in histidine-free medium were then incubated for a 48-h period at 37 °C. Six concentrations were tested, the highest being 32 times more concentrated. According to the kit guidelines, a three-fold and higher increase in the number of revertants relative to the negative control or a clear dose response suggests mutagenicity. Exhaust extracts collected under cold driving conditions for all vehicles were also tested with the mutagenicity Ames test in order to compare the whole GDI fleet with the diesel vehicle.

Results:
The analysis of the PAH contents in GDI exhausts with different fuels revealed that ethanol blends produce lower emissions. Fig. 1 shows the concentration of the sum of the genotoxic PAHs for the different test conditions.
Concentration of PAHs in ng/m^3 of a selection of the most genotoxic PAHs is shown in Fig. 2. In general the Diesel vehicle with filter is the lowest emitter. There are GDI vehicles emitting up to 2-3 orders of magnitude higher emissions.
From the Ames test performed, only one sample (GDI vehicle 1 with gasoline and hot start conditions) at the highest concentration was suggested to be mutagenic with the use of the TA98 strain. However no clear dose-response trend was observed.

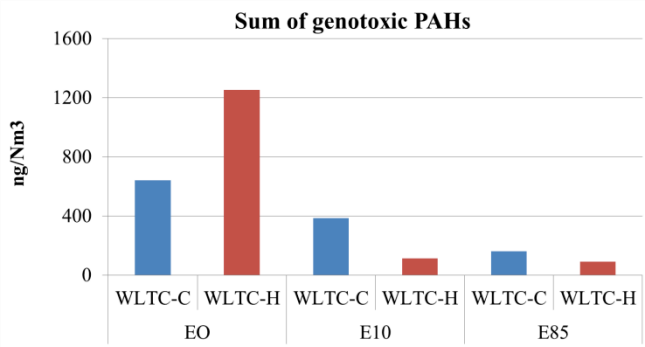

Fig. 1. Effect of ethanol on PAH concentrations (ng/Nm^3) of GDI vehicle V1.

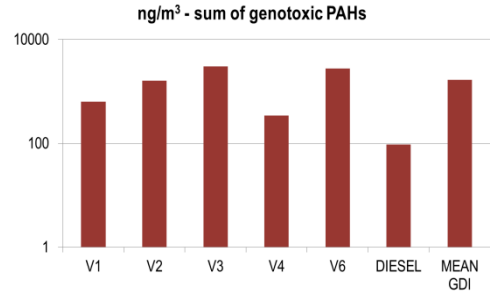

Fig. 2. Comparison of the genotoxic PAH concentrations (ng/Nm^3) of 5 GDI vehicles and one diesel vehicle with filter.

Conclusions:

According to these results it is evidenced that genotoxic PAH emissions are lowered with the use of ethanol. It can also be said that the average emission of genotoxic PAHs for the GDI fleet exceeds that of the diesel vehicle with filter. However, the Ames test results are not conclusive and further analysis with higher concentrations of the extracts should be performed.