Aircraft gas turbine particle emissions in cruise

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The existing global regulation of aircraft gas turbine particle emissions (limits for non-volatile particle mass and number) has been mainly developed related to local air quality concerns. In recent years, the environmental role of aircraft particle emissions at cruise above 8 km of altitude has gained more interest. Particle emission measurements performed at cruise (with chase aircraft) revealed an influence of non-volatile particle number emissions on the number of ice nucleation particles and on the radiative properties of contrails and contrail-cirrus. Recent measurements indicate that volatile particles may play a role, too. Since especially persistent contrails at night can produce a significant climate warming effect, whereas during daytime they can produce a climate cooling effect, reduction of cruise particle emissions and avoiding persistent contrails at night, while not increasing fossil CO_2 emissions are considered important mitigation measures to reduce unwanted short term climate effects from aviation. The presentation summarises the state of knowledge concerning the role of particle emissions in cruise, the gaps in terms of engine dependent particle emission characteristics, the role of Sustainable Aviation Fuels in this context and the activities by aviation regulators to close the gaps.

[1] A New Approach to Estimate Particulate Matter Emissions From Ground Certification Data: The nvPM Mission Emissions Estimation Methodology, Ahrens et al. 2022, https://doi.org/10.1115/1.4055477

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The ubiquitous nature of lubrication oil in aero gas turbine exhausts

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Civil aviation gas turbines utilize unique synthetic aeroderivative lubrication oils, formulated using polyol ester base stocks and various additives for oxidative stability over a wide temperature range. Airport field studies have revealed that lubrication oil is commonly present in organic PM emissions that are associated with emitted soot particles [1] and it was furthermore recently suggested that gas-phase oil molecules could even nucleate particles [2]. However, the dependence of emissions on engine state and technology are not well understood as well as the implications and fate of these emissions for ambient air quality and climate.

This presentation summarizes the highlights of the engine test cell measurements of the ongoing Aviation Plume PROPeRtIes AT point of Exposure (APPROPRIATE) project. Targeted measurements were performed in the exhausts of nine in service aircraft turbofans from two different manufacturers using an Extractive Electrospray Ionization ToF-MS (EESI-ToF-MS) an Aerosol MS (AMS), and a multi-orifice uniform deposition impactor (MOUDI). Aerosol chemical markers of used oil and commonly known oil components (e.g., tricresyl phosphate) were detected in the exhausts of all nine engines. An example for such an oil detection is show in Fig. 1 below which shows the mass defect analysis derived from the EESI-ToF-MS measurement of stock oil (left) and the exhaust of a PW4062A engine (right).

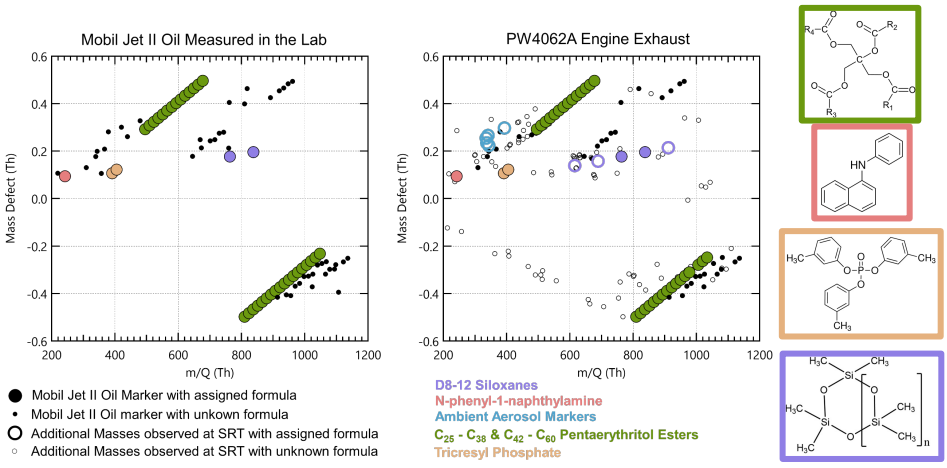

Fig 1 Example identification of jet engine lubrication oil shown as mass defect plots of stock oil (left) and PW4062 gas turbine engine exhaust (right) with their associated molecular structures (color panels on the right)

The thrust dependence and size dependent mixing state of the oil emitted will be further subject of the presentation in addition to the potential implications of this ubiquitous component of aero gas turbine exhaust.

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27th ETH Nanoparticles Conference June 10-14, 2024, ETH Zurich
Conference Topic: Aircraft, marine and other non-road sources

Mobile test rig for field measurement of small jet engine particle emissions

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The Czech Republic has a long tradition in the production of small sports airplanes and gliders and holds a global lead in the number of aircrafts produced per capita. Jet engines, with high thrust to weight ratio and high energy density of liquid fuels, are popular prime movers not only for large, but increasingly also for smaller airplanes. They are also a significant contributor to both health and climate relevant air pollution. To decrease emissions of carbonaceous particles, probably the component most hazardous to human health, with black carbon having also substantial positive radiation forcing effect, the International Civil Aviation Organization (ICAO) standards call for measurement of total mass and number of non-volatile particles on engines with thrust over 22.7 kN, while older filter based smoke number is still used for smaller engines. Unlike with ground vehicle piston engines, the concentrations of pollutants of a jet engine vary across the cross-section of the plume, requiring the coverage of multiple sampling points. **This work describes an innovative mobile test rig for measurement of exhaust emissions from small jet engines in the field, with the test being performed on a stationary aircraft.**

The airplane is secured against a movement in a suitable outdoor location. A sample nozzle (here a 8 mm stainless steel tube) is placed facing into the main jet outlet at a distance of less than its radius, and secured to a stand allowing for probe positioning along vertical and horizontal axes. At a suitable distance from the jet exit plane, the probe transitions to a heated (165°C) sampling line leading to the test rig placed in a tent or in a nearby building. The exhaust sample is split between FTIR analyzer (5 m optical path length, 0.5 cm^{-1} spectral resolution, 5 Hz sampling rate, all gaseous compounds incl. CO_2, CO, formaldehyde, NO, NO_2, NH_3, N_2O, CH_4), a non-volatile particle counting system (NanoMet3, Testo), and a heated ejector diluter (8:1 dil. ratio), feeding, in parallel, into 47 mm quartz filters for thermogravimetric (EC-OC) analysis, glass fiber filters for gravimetry and smoke number, photoacoustic soot analyzer (Microsoot sensor, AVL) for non-volatile particle mass, and fast electric mobility particle sizer (Engine Exhaust Particle Sizer, TSI). At each engine trust level, the exhaust is sampled for approx. 260 s, traversing 21 sample points covering the exit plume, starting and ending at the center point, at 10 s per point plus 2 s transition. This allows for discrete online measurement at multiple sampling points as well as providing a representative sample for smoke number measurement. The result of the EC-OC analysis can later be used to calibrate the photoacoustic black soot measurement. At five minutes per thrust setting, four thrust levels, and three repetitions of the sequence, a total of one hour of tests, less than 2 engine hours are required, and the entire test can be performed in one day.

This approach is demonstrated on a type approval grade test (per European Union Aviation Safety Agency) of an auxiliary TJ42 jet engine with < 10 cm nozzle diameter and hundreds of N rated thrust installed in a G 304JS sailplane (https://hph.cz/products/hph-304s-shark/) with a wingspan of 18 m with an aspect ratio of 27. This measurement has posed an additional challenge: The lubrication of the engine with oil mixed with the fuel has resulted in most of the particulate matter measured being uncombusted lubricating oil, while the emissions of non-volatile particles, both by number and mass, were very low.

Gaseous and Non-Volatile Particulate Matter Turboshaft-Engine Emissions using 30%, 50% and 100% HEFA Sustainable Aviation Fuel

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In this work, the reasons for the reduction in soot particles when using SAF's with different mixture proportions (30%, 50% and 100% HEFA-SPK) are explained based on a measurement campaign carried out on a helicopter engine (Allison 250-C20B) in summer 2023. The gaseous and particulate matter emissions were analyzed at different load levels of the engine. The change of the load level is linked to changes in gaseous and particulate matter (PM) emissions. The emission indices (EI's) for the gas phase are reduced at higher loading points during higher combustion chamber efficiency due to better fuel atomization and higher temperatures. The difference in the gaseous EI's between the fuel-SAF mixing ratios used are negligible for all regulated gaseous compounds (CO, UHC, NOx) and were compared to previous studies [1].

But there is a clear change of the number, mass, properties and formation behaviour of the soot particles using different fuel-SAF mixing ratios. The non-volatile particulate matter (nvPM) number concentration was reduced by up to 80% using 100% SAF compared to standard Jet A-1. Due to the change of the particle diameter, the particle mass reduced up to 40%. Using (low aromatic) synthetic fuel shifts the mode of the particle number size distribution (PNSD) by 50% in diameter (e.g. geometric mean diameter mode for Take-Off for PNSD using 100% SAF: 30nm; compared to Take-Off using Jet A-1: 60nm).

This behaviour can be explained primarily due to the composition of the HEFA fuels. For a detailed comparison of the soot particles the number concentration (CPC), size distribution(SMPS+DMS), mass (gravimetry) and appearance (SEM) were determined.

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Experimental Investigation of Charge on Aircraft Gas Turbine Combustion Engine nvPM

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It is estimated that 16,000 premature deaths are caused by aviation emissions annually[1]. Additionally, aviation emissions have a significant impact on the environment, where they are thought to be the main source of anthropogenic particulate matter in the upper atmosphere[2].

In response to the growing aforementioned concerns, the ICAO has introduced a global nvPM emissions reporting standard to regulate the emitted concentrations of nvPM. The standard is relevant for all in-production and new gas turbine engines above 26.7 kN[3].

Due to the harsh environment at the aircraft engine exit, long sampling tubing is used to transport the exhaust sample to the regulatory measurement systems. The use of long sampling tubing causes significant nvPM losses through various well known mechanisms. To account for the losses, regulations prescribe the use of corrections, which accounts for five main nvPM loss mechanism[3]. One loss mechanism is caused from charged nvPM; however, regulation assumes that nvPM is singly charged and thus has limited impact on the total losses.

Although nvPM is assumed singly charged, limited experimental research has been conducted to validate this assumption. Some theoretical studies have modelled the combustion process in aircraft engines and found that nvPM is likely highly charged[4].

This study aims to measure and quantify the charge on nvPM for various aircraft gas turbine combustion engines, engine power conditions, and fuels types from JetA to SAF drop-ins. The charge has been quantified by measuring the charge fraction of the nvPM, allowing an understand of what sizes of nvPM are charged, and by measuring the mean charge of the whole size range of nvPM. As can be seen from the preliminary figures below, nvPM was found to be charged, with a charge fraction that increases with engine power. Note, further trends were found based on engine power and fuel type.

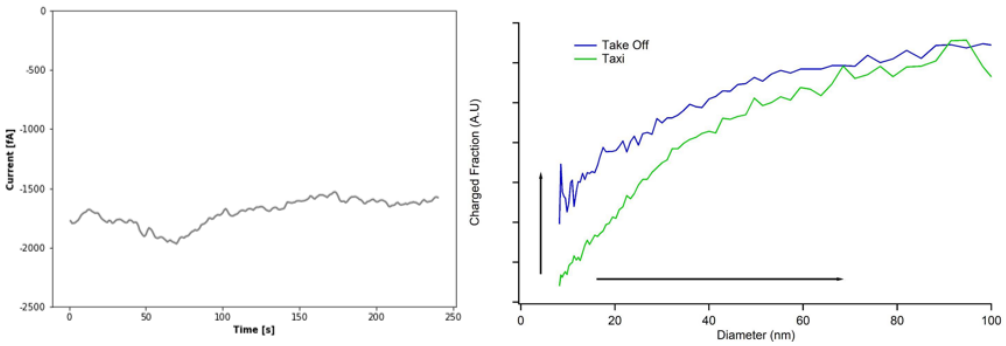

Figure.1: Total Current and charge fraction of nvPM produced from JetA engine test.

This study suggest the possible need of adapting the regulatory electrostatic loss correction, In a wider context, quantifying the charge of nvPM has impacts for local airport air quality studies; cloud studies in terms on understanding the role of nvPM as CCN and INP; and emissions inventory models.

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27th ETH Nanoparticles Conference June 10-14, 2024, ETH Zurich
Conference Topic: Aircraft, marine and other non-road sources

Effects of photochemical aging on the chemical and optical properties of exhaust emissions from a small-scale jet engine burner

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Aviation contributes to local and remote air pollution by emitting ultrafine particles and gaseous pollutants. Especially the compositions of long-transported, atmospherically aged exhausts remain poorly described, even though they may cause major health effects while also influencing the radiative forcing in the atmosphere. Here, our aim is to examine the impacts of photochemical aging on the jet engine exhaust emissions using kerosine-based jet fuel JP-8. The laboratory experiments were performed at the University of Rostock with a test rig containing a combustion chamber of an original small jet engine. The selected stable operation condition was determined so that the fresh emissions were comparable to those of an average land-and takeoff cycle of a commercial aircraft. Photochemical aging was conducted using the Photochemical Emission Aging flow Reactor (PEAR [1]), with hydroxyl radical exposure equivalent to roughly 2 days of atmospheric aging. Further tests at different exposures (0.5 – 7 days) were also performed. Online methods included, for example, high-resolution aerosol mass spectrometer (AMS) and proton-transfer-reaction (PTR-)ToF-MS for analysis of the exhaust chemical composition, scanning mobility particle sizer (SMPS) for the particle size and number determination, 7-λ aethalometer for online assessment of the particle light absorption, and aerodynamic aerosol classifier (AAC) coupled with an SMPS for particle density assessment. Filter samples were employed for a total carbon analysis and determination of the light absorbance of the water-soluble organic carbon by ultraviolet-visible (UV-Vis) absorption spectrophotometry.

Fresh particle emissions were minor, and had bimodal particle size distributions mainly composed of sub-30 nm particles. Scanning electron microscopy imaging confirmed that there was no soot in the exhaust emissions. Photochemical aging led to notable particle growth by substantial secondary organic aerosol formation, which increased the total particle mass by a factor of ~300 while decreasing the size-dependent particle effective densities. Organic aerosol became increasingly oxidized as a function of exposure. Further, aging caused a significant increase in the light absorption by organic matter at lower visible wavelengths (e.g., ×10 at 365nm, based on the UV-vis). The potential climate impact of such secondary aerosol formation is further assessed by modelling of the radiative forcing efficiency based on the aethalometer and UV-Vis results.

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27th ETH Nanoparticles Conference June 10-14, 2024, ETH Zurich
Conference Topic: Aircraft, marine and other non-road sources

Influence of photochemical aging on physical-chemical properties of ultrafine particulate matter from the exhaust emissions of a ship diesel engine

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There is growing concern that exposure to ultrafine particulate matter (UFP), especially from anthropogenic sources such as combustion processes or transport emissions, represents a hazard to human health not covered by current mass-based air quality guidelines. Moreover, the effects of atmospheric aging on the physical and chemical properties of UFP emitted by transportation emissions are largely unknown. This study investigated a one-cylinder ship diesel research engine in a laboratory setup at the University of Rostock. The respective emissions operating with two different fuels (marine gas oil and heavy fuel oil) were examined. Primary fresh exhaust particles and photochemically aged particles were analyzed for their physical-chemical properties and the changes of these properties upon the aging process.

The ship diesel engine was operated according to the test cycle E2 of ISO 8178-4. This cycle consists of four phases with different engine loads (25 %, 50%, 75%, 100% of maximum load), which run for 15 %, 15 %, 50 % and 20 % of the time, respectively. Photochemical aging was conducted using the Photochemical Emission Aging Flow Reactor (PEAR [1]) and was equivalent to roughly 1-2 days of atmospheric aging. Online methods included, for example, scanning mobility particle sizer (SMPS) for the particle size and number determination, a Tapered Element Oscillating Microbalance (TEOM) for particle mass concentration, and an aethalometer for black carbon concentration. Filter samples were taken for chemical analysis. Gas-chromatography/mass spectrometry covered Polycyclic Aromatic Hydrocarbons (PAH) and alkanes; elemental analysis (ICP-OES) selected heavy metals.

Fresh exhaust aerosol particles from the ship diesel engine consists of relatively small particles predominantly in the UFP region. Furthermore, heavy fuel oil exhaust particles transport a large number of various four- and five-ring PAH with them.

Photochemically aging of the ship engine exhaust particles showed a considerable impact on several important metrics for the characterization of ultrafine particulate matter. Particle mass and number concentrations increased upon aging. The mean diameter of the particles also increased after passing the aging device, but still stayed in the ultrafine particle region. The lung deposited surface area was enhanced as well. Aliphatic and aromatic hydrocarbons were reduced by oxidation during the aging process, and the aged particles exhibited an increased appearance of oxygen containing species.

In a follow-up step, correlation with the results from cell exposure experiments that took place in parallel with the same exhaust aerosols will allow a better understanding of the link between physical-chemical data and adverse health effects.

[1] Ihalainen et al. *Aerosol Science and Technology*, **2019**, DOI: 10.1080/02786826.2018.1559918.

Physical and chemical characterization of the particles emitted by a DI SI engine with low- and zero-carbon fuels

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Because of its detrimental effects on human health and the environment, particulate matter (PM) released by internal combustion engines (ICEs) has long been a source of concern. Particle emissions can be greatly decreased by using low- or zero-carbon fuels like hydrogen. Because hydrogen lacks carbon in its structure, particle emissions from its combustion are frequently unexpected. The lube oil in this instance has a strategic impact on the formation of particles, as found in our previous papers [1,2]. In the current study, a comparison of particle and other hazardous pollutants emissions burning hydrogen and a carbon fuel like methane has been performed. The results on physical and chemical characterization of the emissions from the two different fuels were combined to enable a comprehensive investigation of the effects of lubricating oil.
A single-cylinder direct injection spark ignition engine running on hydrogen or methane was used for the experiments. Two operating conditions—2000 and 3000 rpm full load—were tested. An engine exhaust particle sizer connected to a single diluter was used to online characterize the number and size of particles. A condensation sampling line attached to the tailpipe collected the condensed exhaust and particles for off-line chemical characterization using various analytical techniques. Important information on the mechanisms underlying the emission of particles and highly hazardous PAHs was supplied by the spectroscopic and chemical analytical techniques. Soot particles were separated by the soluble organic fraction (SOF).
The amount of particles changes depending on fuel type and engine speed, indicating that the oil plays a different role depending on the environmental factors. Because of the increased temperatures in the combustion chamber that cause the oil film on the cylinder surfaces to burn or oxidize, particles grow as the engine speed and hydrogen fuel combination increases. However, the fuel has the main role. The particle concentration, in fact, increases with hydrogen because of the higher temperature reached in the combustion chamber.

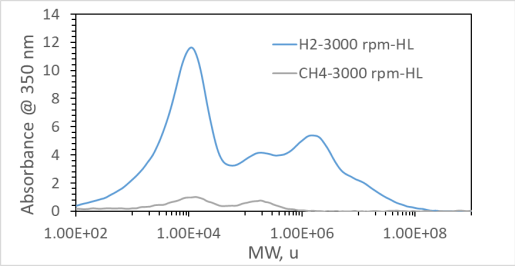

FIGURE 1. MW distribution profiles of the SOF samples from SEC with non-porous column of 3000 rpm samples

Figure 1 reports the molecular weight (MW) distribution assessed off-line on SOF using Size Exclusion Chromatography (SEC) for sample at 3000 rpm. When hydrogen is used as fuel instead of methane at 3000 rpm, there is a higher concentration of particles. Particles were not collected only at 2000 rpm with methane, but the soluble organic fraction's MW distribution indicates the presence of higher MW species at 3000 rpm and a lower concentration of PAH, indicating the role of high MW species in the soot inception.
This study demonstrated that using hydrogen as an ICE fuel can have a greater environmental impact than using a carbon fuel like methane. This highlights the need to optimize the combustion behaviour as well as the lubrication oil properties when the engine is fuelled with hydrogen.

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Emissions of passenger cars with different engine and aftertreatment technologies

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INRODUCTION

Legislative actions and technological development of engines and aftertreatment systems have significantly cut exhaust emissions of vehicles. For instance, NO_x and PM emissions of diesel vehicles have decreased as well as THC emissions in gasoline vehicles when shifting from older Euro 2 and Euro 5 levels to Euro 6 [1]. On the other hand, emissions of some components such as N_2O or NH_3 may even have increased [1].

METHODS

Emissions of passenger cars were tested on light-duty chassis dynamometer in a large joint measurement campaign. Emission measurement setup consisted of legislative measurements and large set of additional measurements. Here, gaseous emission data from Fourier-transform infrared spectrometer (FTIR, BOB-1000, Best Instruments Co. Ltd.) will be presented with focus on unregulated emission species.

Emission tests were conducted for 7 vehicles with different type of power train technologies and aftertreatment systems. Emission levels ranged from Euro 4 to the newest Euro 6. Two plug-in hybrid vehicles were included in the tests as well as one compressed natural gas (CNG) vehicle. Emission tests were conducted on a chassis dynamometer with a cycle derived from real driving. Temperatures in the dynamometer space were varied between -9 and 35 °C.

RESULTS

In general, the newest vehicles produced only low emission of traditional pollutants such as CO, NO, NO_2, especially compared to older Euro 4 diesel vehicle as illustrated in Figure 1 for NO_x. The newest vehicles with diesel engines produced more N_2O than other vehicles, see Figure 1. Euro 4 diesel vehicle produced similar N_2O concentrations as gasoline and CNG vehicles. The N_2O emissions were most likely originating from the exhaust aftertreatment system as an earlier study suggests [2]. NH_3 was detected from exhaust of vehicles with gasoline and natural gas engines, except one Euro 6 gasoline vehicle produced almost

zero NH_3 concentrations, similar to diesel vehicles. Previously, natural gas heavy-duty vehicles have been found to emit NH_3 [2], and our results indicate similar behaviour.

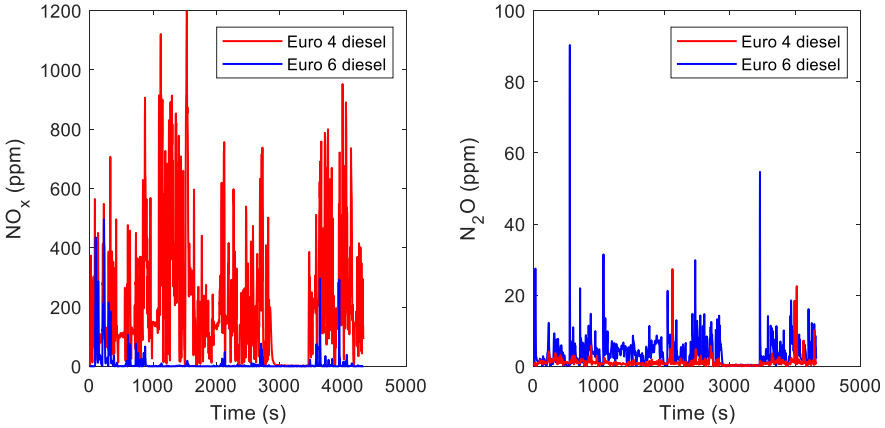

Figure 1. Example time series of NO_x and N_2O tailpipe concentrations from two diesel vehicles with different emission levels.

CONCLUSIONS

The newest technology was seen to cut most of the emissions species. However, components such as N_2O or NH_3 were emitted in similar or even higher levels by the newest vehicles.

ACKNOWLEDGEMENTS

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Real driving solid particle number emissions from a hydraulic hybrid heavy commercial vehicle and diesel sports utilities vehicles in Australia

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Diesel particulate filters (DPFs) are an essential technology for meeting legislated solid particle number (SPN) emission limits. Internationally, real driving emission measurement of SPN is now routine; however, in Australia no data currently exist in the public domain, largely due to lagging behind European emission standards by more than 10 years. Key features of the unique Australian vehicle fleet that make analysis of real driving SPN measurements of interest in an international context include: (i) different fuel quality standards (i.e. especially in terms of sulphur and aromatics content), (ii) variable climate conditions, (iii) slow uptake of electric vehicles, (iv) lack of periodic technical vehicle inspections, (v) a high proportion of heavy passenger vehicles (i.e. sports utility vehicles), (vi) and a high proportion of automatic transmissions and four-wheel drive functionality in the light duty fleet [1].

Our study provided the opportunity to explore DPF regeneration events from a hydraulic hybrid heavy-duty commercial vehicle and two sports utility vehicles (SUVs). During DPF regeneration events (Figure 1): (i) SPN is increased by more than two orders of magnitude for the heavy commercial vehicle and exceeds legislated Euro IV SPN limits by approximately one order of magnitude, (ii) SPN is increased by approximately one order of magnitude for the diesel SUVs; however, the Euro 5 SPN limit is not exceeded. Activation of the hydraulic energy recovery system was successful in reducing SPN by 40% (on average) across three replicate tests.

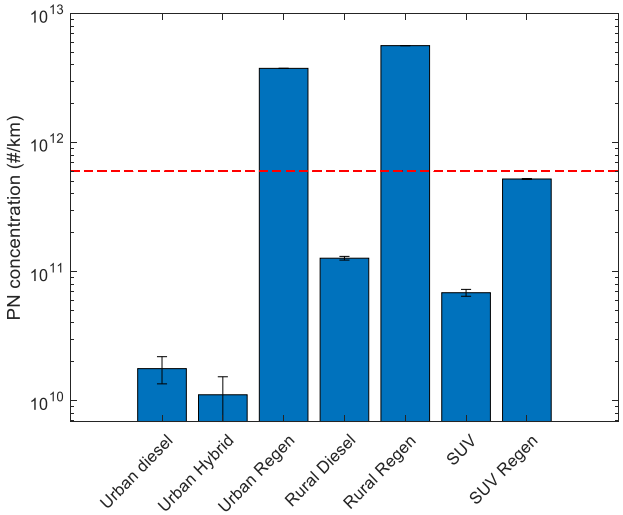

Figure 1: Real driving PN emission rates (#/km) for a hydraulic hybrid heavy commercial vehicle and two Euro 5 SUVs. The Euro PN limit (6×10^{11} #/km) is shown (---). Uncertainties are standard errors of the mean for replicate testing.

At present, the only mechanism to trigger laboratory testing of on-road vehicles in Australia is based on public observation of visible smoke emitted by vehicles and active reporting to the authorities. We recommend that more extensive testing of DPF performance is required in the Australian context to assess their in-use performance that will inform effective SPN control measures and progress towards cleaner mobility solutions.

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Acknowledgements

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Evaluation of a miniaturized exhaust emission measuring system for L category Vehicles measurements in real world driving conditions

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Introduction

Legislation regarding emission standards for L-category vehicles is less strict than passenger vehicles[1] also resulting from a lack of standardized methods of measuring this type of vehicles in real-world driving conditions. The equipment used to measure vehicle emissions while operating in real driving conditions is the Portable Emissions Measurement Systems (PEMS) that has also been incorporated into regulations for Real Driving Emissions (RDE) testing in Europe, which is difficult up to impossible for some motorbikes due to size and weight limitations [2]. SEMS systems have the potential to fill this gap or become a screening tool for identifying high emitting motorbikes. The goal of this study is to demonstrate such a system that includes low-cost ambient gas sensors and an optoacoustic BC sensor[3], and to assess this system in real-world driving conditions for various types of L-category vehicles while focusing on the sensitivity and reliability of the implementation.

Methodology

At first, simulations of Real Driving Emissions (RDE) trips on chassis dynamometer were performed while also using standard lab-test equipment like CVS for sampling and reference instruments such as the MSS. For conducting measurements directly from the exhaust, a dedicated sampling and an adjustable dilution system have been designed to accommodate for small flow and avoid pulsations that are frequently coming from the exhaust of motorbikes. This also makes the use of typical Exhaust Flow Meter (EFM) devices impossible, so other alternatives are explored such as calculations based on transient engine variables (e.g. lambda, MAF, MAP). RDE cycles were subsequently performed with the SEMS system on the road for different motorcycles. RDE testing is designed to capture a wide range of real-world driving scenarios, ensuring that emissions data accurately represent typical driving patterns for each subcategory of L-vehicles.

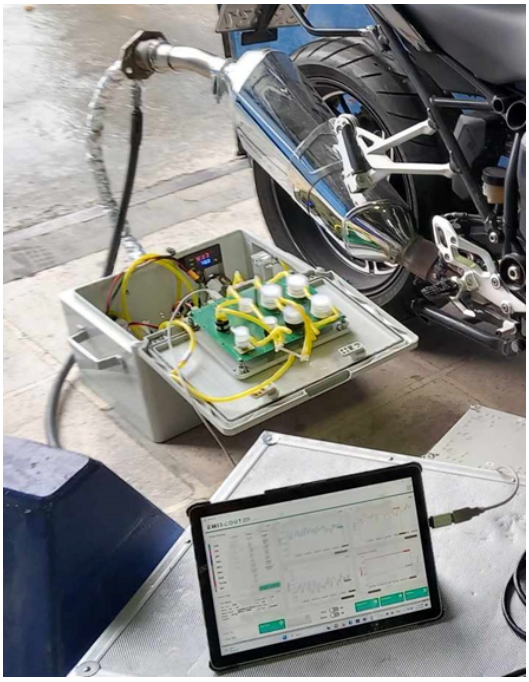

Fig. 1: Experimental setup for motorbike measurements

Results & Conclusions

The emission measurement components of the SEMS comprise commercial electrochemical sensors for measuring CO and NO gases concentration, commercial NDIR analyser for measuring CO2 gas concentration and a prototype optoacoustic sensor for measuring BC mass concentration. Validation of the SEMS system is performed in comparison with PEMS measurements with a WMTC cycle on the chassis dyno. Comparison between chassis and real-world measurements evaluate whether there are significant differences in exhaust concentrations and presumably spot high emitters (especially for CO and BC) among different types of L-category vehicles. This study demonstrates the use of a Sensor-based Emissions Measurement System for main gaseous pollutants (CO2, CO, NO) and BC particles for which no other instrument is available for on-road exhaust measurements. The results contribute towards developing a low-cost portable system for real-driving condition measurements of L-category vehicles for which real-world emission control is rather challenging at the moment.

Acknowledgments

This research has been co-financed by the European Union's Horizon 2020 research and innovation programmes under grant agreement No 862811 (RSENSE) and grant agreement No 101056777 (LENS)

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Assessment of pollutant emissions including ultrafine particles down to 10nm of high-performance motorcycles – lab and real-world evaluation using advanced PEMS technology

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This work presents a comprehensive assessment of pollutant emissions, including ultrafine particles down to 10nm, emitted by high-performance motorcycles. Despite the absence of specific particulate number limits for motorcycles in the European Union, previous in-lab measurements have revealed significant particle number emissions from two-wheelers, with an average particle size of approximately 10-50nm. Notably, a considerable proportion of these particles fall below the current particulate number counting cut-off specified for passenger cars (D50 @23nm).
These investigations further pronounce the presence of high particle formation rates during acceleration, attributable to fuel enrichments, even within the WMTC, the homologation test cycle for motorcycles, which traditionally require moderate power demands. In anticipation of even higher particulate emissions under real-world driving conditions, an evaluation of a lightweight portable emission measurement system (PEMS) is presented. The verification process utilizes a two-wheeler chassis dynamometer with laboratory measurement technology using an RDC, which has a significantly higher power requirement, thereby better reflecting real-world driving conditions than the WMTC.
This evaluation incorporates updated analysers and conditioning systems tailored for assessing solid particle number emissions as small as 10nm. To achieve this, the methodology incorporates calibrated Condensation Particle Counters (CPCs) alongside catalytic strippers in both laboratory and PEMS setups, ensuring accurate quantification of ultrafine solid particles.
Moreover, this paper provides insights into the real-world emissions of a high-performance motorcycle, with particular emphasis on highly dynamic driving scenarios reaching speeds of up to 160km/h. The PEMS utilized in this study is meticulously described, including its design and mounting configuration on the motorcycle, facilitating a detailed understanding of the measurement setup.
In summary, the findings shed light on the previously overlooked aspect of ultrafine particle emissions from motorcycles and highlight the importance of advanced PEMS technology in accurately quantifying these emissions also under real-world conditions.

Strategies for particle emission control from gas fuelled Heavy-Duty engines: potentiality of filter technology

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The increasingly urgent decarbonisation issue, hand in hand with the upcoming restrictive Euro VII regulations on particulate emission, have reinforced the interest in Natural Gas Heavy-Duty engines for the transport sector and, contemporary, the need of specific technologies for the abatement of such pollutant.

Different approaches have been followed by the authors during the recent years and the potentiality of the investigated technologies has been assessed. Acknowledging in lube oil consumption mechanisms the main cause of particles emissions from gas fuelled engines [1], the improvement of the engine ring-pack design and the optimization of the oil formulation revealed strong tools in such sense [2, 3].

An interesting solution to pursue the more and more challenging emissions targets is represented by the use of dedicated aftertreatment systems, composed by the standard Three-Way Catalyst, for the conversion of gas-phase criteria pollutants in conjunction with Particulate Filters for the abatement of exhaust particles [4, 5].

In the present study, the performance of a cordierite filter was explored through an extensive experimental campaign, running a Natural Gas Heavy Duty engine compliant with the last Euro VI regulation. The filtration efficiency was analysed in terms of particle number, mass and size distribution upstream and downstream the ATS, over the World Harmonized Transient Cycle (WHTCs).

The adopted particulate filter showed very high filtration efficiency (about 98%), evidencing interesting potentiality of such systems and giving the basis for further insights on different aspects highlighted during the experimental campaign. The exploited technology can represent a feasible way for the compliance of future Heavy-Duty engines powered with low or zero-carbon fuels, like biomethane or hydrogen, representing a mid-term solution for the sustainability of the transport sector.

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Innovative Gasoline Particulate Filters: A Comprehensive Analysis of Intrinsic High Filtration Rates and Operational Performance

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This scientific contribution explores a novel class of gasoline particulate filters designed with an intrinsic high filtration rate. Distinguished from conventional vehicle particulate filters, the enhanced filtration efficiency of these filters is achieved through a unique pore structure, eliminating the dependence on soot layer buildup for optimal performance.

The inherent characteristics of these innovative filters make them particularly suitable for application in gasoline engines and other applications where particle mass is minimal but ultrafine particles such as viruses. The paper meticulously compares conventional filters lacking a specialized pore structure with the newly developed filters, discussing disparities in filtration efficiency over time and under varying load conditions.

Furthermore, the study presents a comparative analysis of the filters' performance in both diesel and gasoline engines, conducted on a test bench and within the context of actual vehicle operation. This research sheds light on the transformative potential of these advanced filters in redefining filtration standards across diverse operational scenarios.

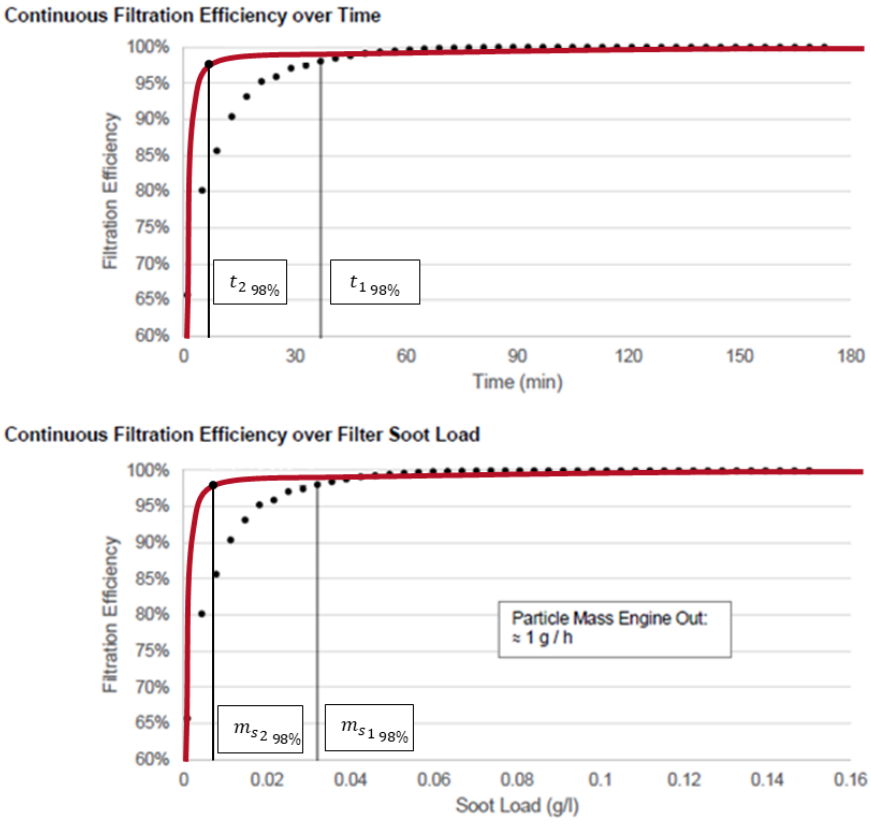

Figure 1: Filtration of the novel (red, full) and conventional filters (black, dotted) depending on the time and loading of the filter

Particle number emissions from a hydrogen-fueled Turbulent Jet Ignition engine with a passive prechamber

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Modern combustion systems are increasingly being used to burn hydrogen. In such a direction, research has been conducted using a Turbulent Jet Ignition (TJI) system with a passive prechamber. The TJI system allows the combustion of lean mixtures and such a solution was used in the current work.

The purpose of the work was to analyze particle number emissions using the TJI system under passive chamber conditions. The work was conducted with:

- two engine speeds (n = 1200; 1500 rpm)
- high value of the excess air coefficient (λ = 1.65; 2.0; 2.2)
- varying values of the indicator referred to as the center of combustion (CoC = 6; 8; 10 deg aTDC).

The study used a single-cylinder AVL5804 research engine with a two-stage combustion system equipped with a hydrogen injection system (P = 9 bar) into the intake channel. The prechamber was equipped with a spark plug.

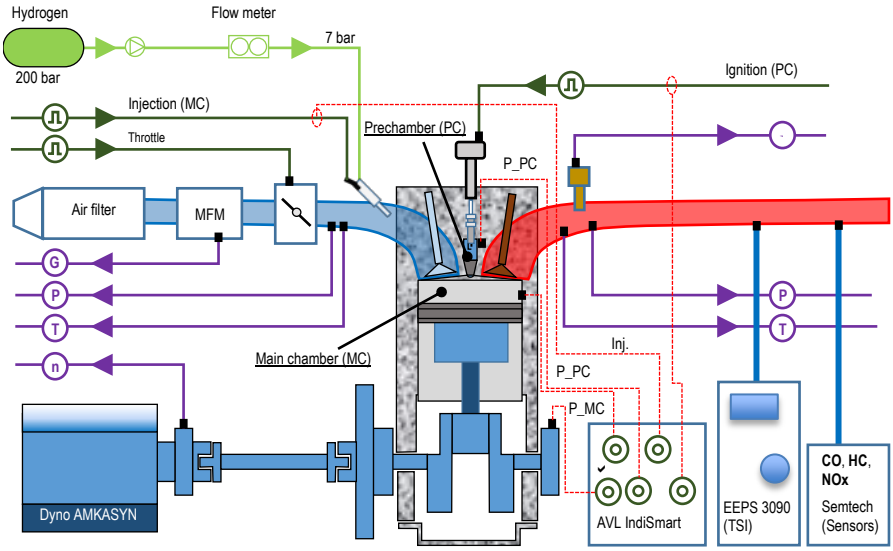

Fig. 1. Scheme of the test stand with measuring apparatus

The concentration of gaseous toxic components and the concentration of particle number were analyzed under static conditions. The analysis of the concentration of gaseous components shows their global reduction when the angle of the center of combustion (CoC) is increased (related to ignition retardation). The largest reduction is in the concentration of nitrogen oxides. Change in λ-coefficient from 1.65 to 2.20 results in a more than 5-fold reduction in their concentration. The carbon monoxide content is mainly due to the combustion of lubricating oil (consider that this is a single-cylinder engine). Analysis of the test results indicates that there is a relationship between the excess air factor and the

concentration of particle number. The total number of particles in the range λ > 2.0 indicates a higher number at lower engine speed. The effect of CoC is ambiguous when changing engine speed and excess air ratio. At low λ, it has been shown that engine speed has a much greater effect on particle number than combustion center angle (CoC).

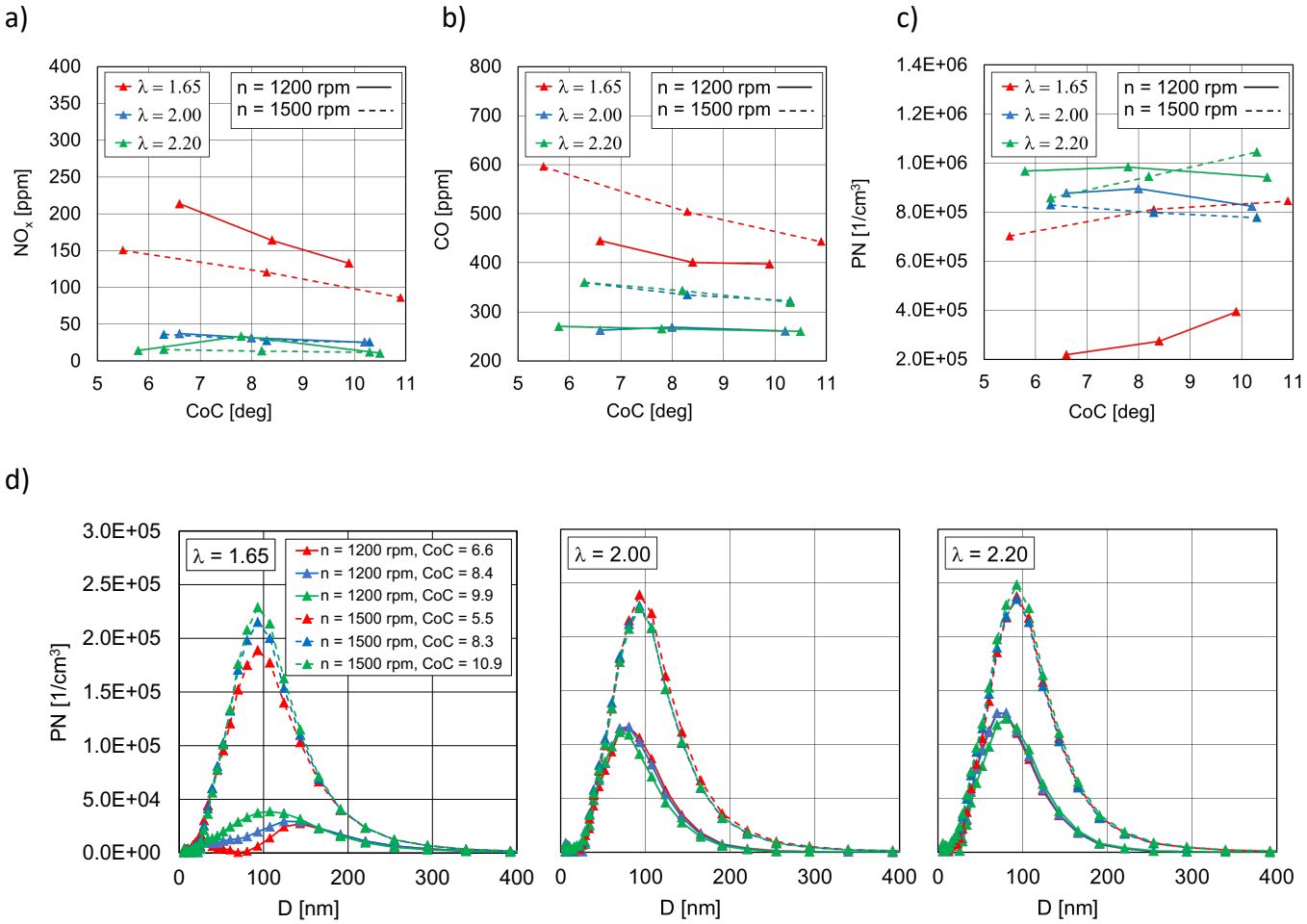

Fig. 2. Results of tests of exhaust gas components under different operating conditions of a hydrogen-fueled engine: a) concentration of nitrogen oxides; b) concentration of carbon monoxide; c) concentration of particle number; d) concentration histogram particle number at different values of excess air coefficient – λ

Analysis of the test results indicates that increasing the speed of rotation results in a more than 2-fold increase in the number of particles. It should be noted that changing the angle of the center of combustion has little effect on changes in the characteristic diameter of particles. Although the increase of λ affects the reduction of the concentration of all analyzed gaseous components, it does not affect the shape of the particle number histogram. It can be concluded that increasing the excess air ratio slightly increases the maximum values of particle number concentration in the range of 80–100 nm (regardless of the speed). For the SIDI engine, other researchers also obtained a 2-fold increase in particle number (relative to the PFI engine) in the range of about 10 nm [5].

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The Dirty Tail of Vehicle Fleets and how to Detect and Clean the High Emitters - the Fastest Route to Clean Urban Air at Low Cost

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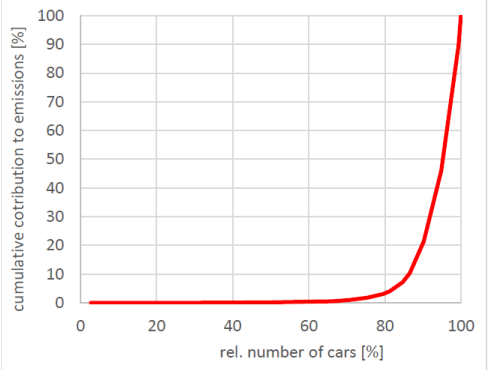
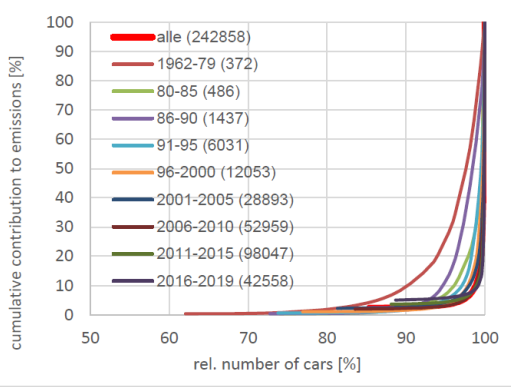
Homologation, Conformity of Production COP, In Service Conformity (ISC) and Surveillance Monitoring take care of systematic deteriorating effects of emissions given by the applied technology and established production quality.

But, what about wear, random failures, maintenance negligence and intentional manipulation, which might have much stronger influence on urban air quality than built-in and well controlled systematic deteriorations? Recent vehicle emission history has clearly demonstrated that these statistics and manipulative effects can increase emission levels by several orders of magnitude above limit values and are not necessarily detected by most modern on-board control since even OBD seems to be an easy target for manipulation.



PN at idle of 1000 Diesel vehicles in Zürich with DPF



PN at light load of 400‘000 petrol vehicles in the city of Mexico

This risk of deterioration has become larger with introduction of emission control elements like DPF, DOC and SCR since these technologies are expensive to replace, temptation for manipulation is increasing. These statistics tell us, that a few cars, maybe 2-3% of the fleet – overaged, damaged, deteriorated or manipulated, dominate the pollution of urban air. Repairing or scrapping them could reduce PN pollution and also other toxic air contaminants immediately and by a very high degree as well as at low cost. But we need to identify them – and this requires frequent full fleet periodic technical inspection (NPTI).

Why choose PN as the flagship metric for air pollution?

- because it dominates the health risk in urban air;
- because it is the most sensitive criterion, easy to control, monitor and quantify;
- because it characterizes the main contributor of the internal combustion engine best;

This new testing method will be described as well as the instruments which have been developed by the international VERT-NPTI working group during 2016-19 and now implemented in four European countries for testing of DPF-equipped Diesel vehicles. The target, however, is, to use this tool for all vehicles and also to find out which technical measures can be recommended to mitigate the high emitters. Preliminary results from a NPTI testing campaign of 1000 gasoline within the Horizon Europe AeroSolfd project are also presented.

Integrated PN measurement system performance and VPR requirements

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Volatile particle removal (VPR) is a requirement for certified particle number (PN) emission measurement from the exhaust sample measurements to allow reproducible measurement of the exhaust particle concentration. The volatile particles are particles as well as the soot, but since they are in vapour phase when passing through the exhaust aftertreatment system and more importantly, can transform between different phases outside of vehicle, even in the measurement system.

Vehicle type approval requirements (PMP) effectively specify a method for volatile particle removal instead of performance to achieve a required result [1]. This requirement is based on fully specifying the measurement system to avoid reproducibility issues with different vendors. In the case of periodic technical inspection (PTI) the requirements in several countries specify performance for the devices instead of a method [2]. This fundamental difference in the requirements has opened the field on PN measurement to many different technologies resulting in constant optimization and continuous improvement.

We present a solution that passes the tests for VPR performance at much lower temperature than PMP requirement. The active part of the instrument is kept at high temperature and the construction is integrated, combining the VPR and sensing unit. This allows the volatile particle removal to be achieved at significantly lower temperature than in the vehicle emission type approval specification. This simplicity of construction and measurement operation allows for more robust and economical construction and operation than previously possible.

We present results from PN measurements from vehicle emissions as well as validation against tetracontane challenge particles, using Pegasor G2 sensor developed and certified for PN measurement for particle size range from 23-200nm.

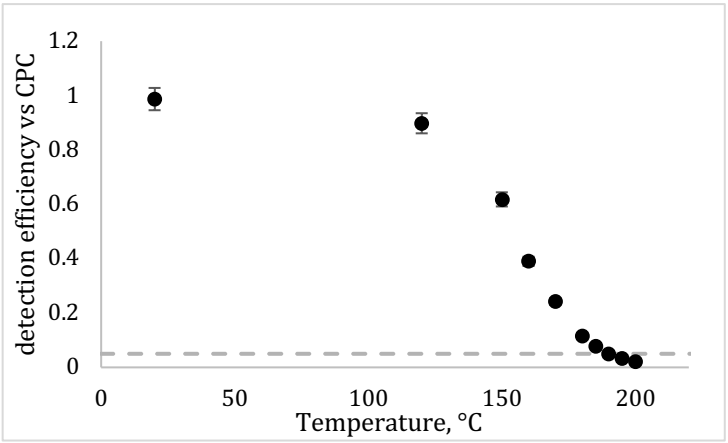

Figure 1 Pegasor G2 detection efficiency for 116000 #/cc, 30 nm tetracontane particles versus VPR temperature. Dashed line shows regulatory requirement.

The VPR has an essential role in vehicle exhaust PN measurements, but when overspecified, especially method-driven requirements cause additional costs, safety issues, error sources and complexity compared to technology neutral, performance-based requirements. Pegasor G2 has certified, unique approach to VPR that brings benefits to end user, while fully committing to the measurement quality and requirements.

Acknowledgement
VPR Tetracontane tests measured at METAS by Kevin Auderset

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Primary and secondary emissions of pellets, logwood, and oil residential heating appliances: emissions factors, secondary particle formation and particle effective density

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Residential wood combustion is the main source of fine particulate matter ($PM_{2.5}$) in winter. This source also emits large quantities of organic species, covering a wide range of volatility, which through photo-oxidation processes in the atmosphere lead to the formation of secondary organic aerosols (SOA) significantly contributing to ambient air $PM_{2.5}$ concentrations. The potential and processes of SOA formation from these emissions are still poorly understood [1]. As the literature on the emissions from residential pellet appliances (stoves and boilers) is quite scarce, it is essential to improve the knowledge on their primary emissions, notably black carbon (BC), and their potential to form secondary particles. This work focused on the evaluation of the primary and secondary emissions from three modern stoves and three modern pellet boilers and their comparison to other fuel-fired residential appliances (a logwood boiler, a stove, and an oil boiler). The impacts of the output (nominal, reduced, and intermediate), as well as the composition of the pellets (softwood or hardwood), were also evaluated. After dilution (20-50 times), emissions were aged using a potential aerosol mass-oxidation flow reactor (PAM-OFR) with OH radical at ambient temperature and environmental relevant relative humidity (40-60%). The formation of secondary particles by nucleation processes was also investigated by filtering (HEPA filter) the entering emissions into the PAM-OFR. Primary and secondary emissions were measured on-line using a high resolution-time of flight-aerosol mass spectrometer (HR-ToF-AMS), a scanning mobility particle sizer (SMPS), a condensation particle counter (CPC), a multi-wavelength aethalometer, a proton transfer reaction time-of-flight mass spectrometer (PTR-ToF-MS) and gas analyzers (CO_2, O_2, CO, NOx, total VOCs) providing information on the particulate and gaseous chemical composition, particulate size distribution, and number concentration. Effective particle density at different aerosol size ranges has been investigated by combining a differential mobility analyzer (DMA) and a centrifugal particle mass analyzer (CPMA). Finally, samples (filters and adsorbents) have been manually collected at the emission and after dilution to carry out offline gravimetric and chemical analysis.

The measured primary (notably PM and BC) and secondary emissions will be compared and discussed in terms of wood-burning appliances, terms of use, and fuel burnt. The impact of the residential heating appliance operating conditions, as well as the photochemical aging, on particle effective density and morphology will be also presented.

This work was supported by ADEME (Agency for ecological transition) under grant 206C0004 (research project EPOCHAG) and the French Ministry of Environment.

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27th ETH Nanoparticles Conference June 10-14, 2024, ETH Zurich
Conference Topic: *Biomass-, bio-fuel and synfuel combustion*

UFP and Black Carbon emissions from Real World Wood Stoves without and with Electrostatic Precipitators

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In Berlin a large pilot program started recently with the goal to retrofit up to 100 real world stove with electrostatic precipitators from four different manufactures in a small area in the southwest of Berlin. On each stove measurements of ultra fine Particle and black carbon emissions will be measures after installation and two times in the next two years. For the UFP the test protocol of the German environmental label „ Blue Angel“ for wood stove are used. The test protocol will be presented as well a new instrument to measure Black Carbon at the exit of the chimney.

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On the emissions of wood-log fueled fireplaces: correlation of continuous gas sensor data with particle spectra analysis

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Wood-log fuelled fireplaces in domestic households are widespread. Biomass combustion saves fossil resources, but emissions from such stoves might affect human health. Especially fine dust emissions appear carcinogenic. Automatically controlled combustion might be a solution for future wood-use in heat generation. For that purpose, sensors installed in the flue gas should give continuous and reliable insights concerning gaseous and particulate matter emissions. Resistive particle sensors are known from automotive applications. Typically, they are operated discontinuously: As long as soot deposits on the electrodes, an increasing current signal can be measured. After a certain time, the sensor has to be regenerated at higher temperatures (soot oxidation). Figure 1 shows an initial test with a simple soot sensor (own development, details in [1-4]), installed in the flue gas of a single-room fireplace (LEDA Unica, Germany). Several slopes could be evaluated and correlated with data from a continuous particle analysis (DMS500, CAMBUSTION) – here the product of the "Aerosol Mode Concentration" (i.e. the particle number concentration, PNC) and the "Aerosol Mode" (i.e. count media diameter, CMD).

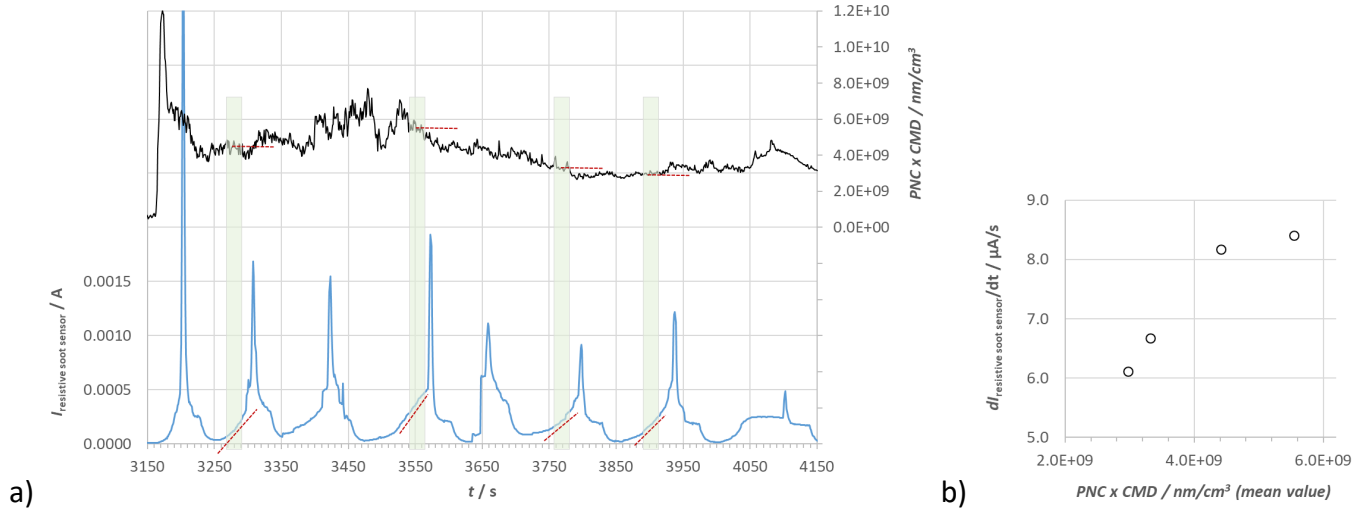

Figure 1a: Comparison of particle analysis (DMS500, CAMBUSTION, details see text, upper curve) and discontinuously operated resistive soot sensor (own development with Pt-electrodes on alumina substrate without protection cap) during wood combustion (starting after stoking with wood in the hot stove); **b**: Correlation of the sensors slope (i.e. increasing current over time during soot deposition on the electrodes) with mean-value of particle data at evaluated time intervals (20 s each, see Figure 1a).

More desirable and effective for controlling the stove operation [5] would be a continuous signal, corresponding to the emissions. For that purpose, a robust gas sensor was developed. It measures a sum of reducing gas components by means of exothermicity (details in [5]). The sensor signal is processed to a concentration value which fits well to data from FTIR gas analysis (MKS Multigas). Figure 2 shows that continuously measured gas data also correlate with particle data. Future work will focus on dependencies between particle formation, various gas sensor data and available operation parameters. A deeper understanding should enable efficient and environmentally friendly biomass use.

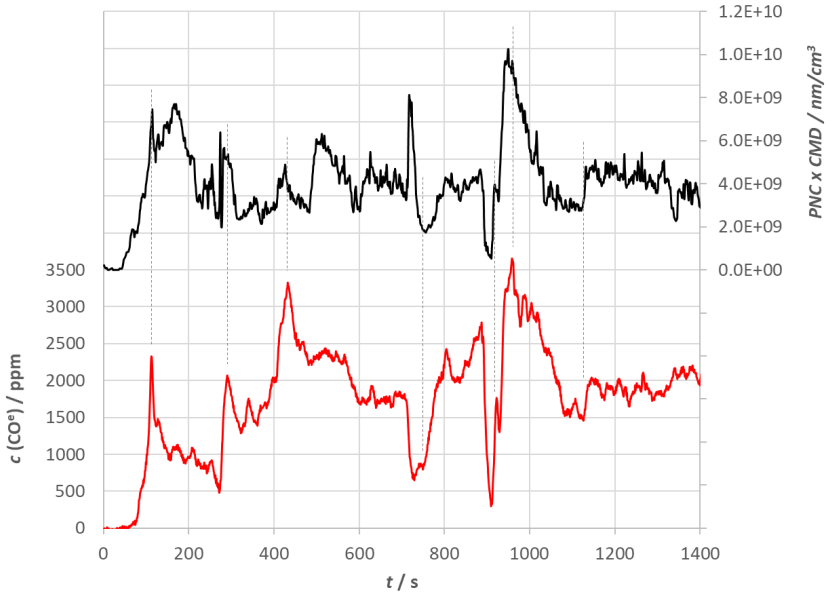

Figure 2: Comparison of particle analysis (DMS500, CAMBUSTION, details see text, upper curve) and sensor signal (SUM of reducing gases as CO-equivalent value by own developed CO/HC-thermoelectric gas sensor after [6], lower curve) during batch combustion of wood in a single room fireplace (cold start and one time stoking with additional wood at *t* = 900s).

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Emissions of an agricultural tractor with experimental e-diesel and commercial diesels

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INTRODUCTION

Electrofuels synthetized from CO_2 and H_2O with renewable or nuclear energy could be used to replace fossil fuels. Diesel engines will remain dominating in some transport sectors, particularly in the heavy-duty transport and shipping resulting that diesel fuel will be needed in the future. Sustainable alternatives for fossil diesel exist, such as diesel produced from waste materials, but also new ones are studies to fill the large demand. One of the new alternatives is the e-diesel (electrofuel), see e.g. [1].

In this work, carbon capture and high-temperature water electrolysis techniques as well as the reverse water-gas shift reaction were used to produce CO and H_2, which acted as feedstocks of Fischer-Tropsch (FT) synthesis. The FT synthesis produced a mixture of hydrocarbons with different chain lengths. Oil refining techniques such as isomerization and distillation were utilized to produce e-diesel from the FT synthesis product. The e-diesel consisted mostly of alkane hydrocarbons and its cetane number (IQT) was 66.1.

METHODS

Emissions of an agricultural tractor (Valtra 235D) running with the e-diesel were studied in a dynamometer and in on-road measurements. Measurements were conducted before and after the aftertreatment system (ATS). The before aftertreatment measurement provided information on the combustion behaviour of the fuel and after aftertreatment provided tailpipe emissions of the tractor. To see differences in the emissions, several different fuels were tested: fossil EN590 diesel, HVO-type renewable diesel, e-diesel and blend of fossil and e-diesel (appr. 35 % of e-diesel).

Emissions of gaseous compounds were measured with AVL PEMS system (Before ATS) and A&D FTIR-spectrometer (After ATS)). Particle number emissions (PN) were measured with the AVL PEMS system (Before ATS) and Dekati MPEC+ (After ATS). AVL Micro Soot sensor was used to study black carbon (BC) concentrations before the ATS.

RESULTS

The fuel affected significantly on the before ATS emissions. For instance, the BC concentrations varied in the order of tens of percent between the fuels as seen from the time series presented in Figure 1. The e-diesel produced the lowest BC concentrations, HVO produced slightly higher than e-diesel and the fossil

EN590 diesel clearly the highest BC concentrations. Blending of EN590 with e-diesel reduced BC emissions by -16 %.

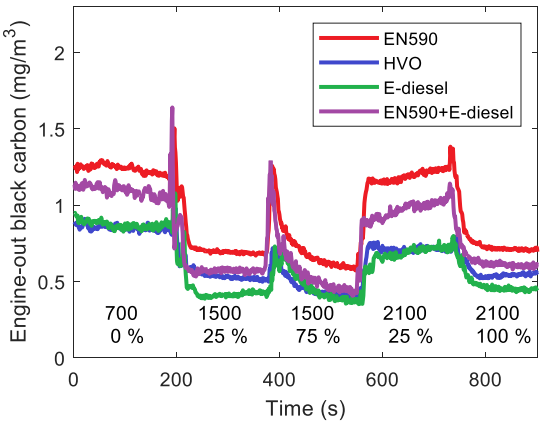

Figure 1 Engine-out black carbon concentrations with different fuels over the dynamometer cycle. The engine rpm and load (%) are marked into the lower section of the figure.

Although fuel affected before ATS concentrations, exhaust exiting from the tailpipe had very low PN concentrations with all fuels and differences between the fuels were not seen. PN concentrations after ATS were not systematic and probably depended mostly on the operation of the diesel particulate filter.

CONCLUSIONS

Experimental e-diesel was manufactured from CO_2 and H_2O and electrical energy. The produced e-diesel proved out to burn well with low black carbon (soot) emissions. In the future, if e-diesels are manufactured commercially, they or their blends with conventional diesel could be used to power the oldest vehicles with the lowest level emission control technology to minimize emission. With the newest engine technology, e-diesels could reduce regeneration needs of the diesel particulate filter.

ACKNOWLEDGEMENTS

This work was conducted under E-fuel project funded by Business Finland (Grant. 43287/31/2020).

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27th ETH Nanoparticles Conference June 10-14, 2024, ETH Zurich
Conference Topic: Biomass-, biofuel- and synfuel combustion

The effect of hydrogen addition on the aerosol properties of combustion generated nanoparticles from premixed ethylene flames

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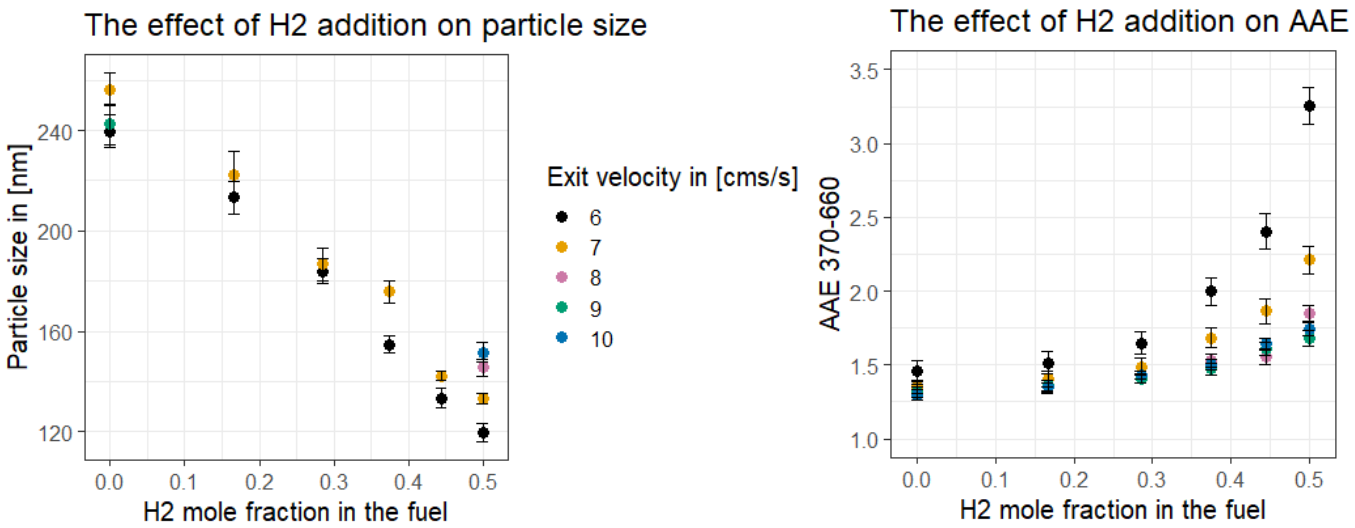
Black carbon (BC), or soot, induces significant climate warming by multi-wavelength radiation absorption. Colored organic carbon (brown carbon or BrC) contributes significantly as well in the near-UV region. This study explores optical, physical, and thermo-chemical properties of combustion-generated carbonaceous aerosols. Using premixed burner-stabilized 1-D flat flames with varied H_2/C_2H_4 ratios and exit velocities 6 to 10 cm/s to account for flame temperature. The equivalence ratio (fuel to air) is maintained at 2.3, the study spans hydrogen fractions in the fuel from 0% to 50%.

An AE43 aethalometer is used in parallel to filter sampling to compute the Angstrom Absorption Exponent (AAE), OC/EC ratios and the Mass Absorption Cross section (MAC) of both BC and BrC. Additionally, sampled aerosol is methanol-dissolved to find the Mass Absorption Efficiency (MAE) of the BrC. A Scanning Mobility Particle Sizer (SMPS) is used to analyze aerosol size distribution. Preliminary results for particle size and AAE are presented below.



All values for AAE were found to be well above 1, indicating the presence of BrC in all conditions. Increasing H_2 mole fractions increase the AAE and roughly halves the mean particle size, especially at lower exit velocities and thus colder flames. The AAE exceeds 3 and the mean particle size decreased from 240nm to 120nm. A larger AAE corresponds to more light absorption by BrC due to the larger AAE of BrC compared to the AAE of BC. Hydrogen addition has a larger effect on the particle size and change in AAE compared to flame temperature. Our current hypothesis states that BrC may serve as precursor for BC formation, given its smaller size and incomplete transformation to BC under conditions characterized by colder flames or elevated H_2 concentrations in the fuel.

Revisiting the Trojan Horse Effect – On the role of lipophilic chemicals in the toxicity of fine and ultrafine combustion particles and implications for regulatory needs

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In Greek Mythology Odysseus and a troop of Greek soldiers hid inside the Trojan Horse to enter the walled city of Troy and win the war. This has become a frequent metaphor of tricks to invite or smuggle something harmful into a protected area. In particle toxicology the "Trojan Horse effect" postulates that particles mediate much of their effects by acting as carriers of harmful soluble components such as organic chemicals and transition metals. However, instead of hiding inside, these soluble components cling highly "visibly" to the outside of what is often a tiny particle core. Moreover, while the original Trojan Horse facilitated transportation across the otherwise impenetrable walls of Troy, many soluble components easily slip through biological barriers often leaving the solid particle core behind, more like a car parked at the gates.

This talk will discuss the importance of lipophilic organic chemicals in mediating cardiopulmonary effects from combustion particles. Decades of toxicological research have shown that lipophilic compounds are rapidly taken up in cells through passive diffusion and may be transported into circulation within minutes through the transcellular route, faster and to a larger extent than the solid particles on which they arrived. Focus will be given on the role polycyclic aromatic hydrocarbons (PAHs) and the aryl hydrocarbon receptor (AhR) in intracellular signalling and regulation of inflammatory reactions in lung epithelial cells and vascular endothelial cells. These effects may not be restricted to classical AhR activating PAHs such as benzo[a]pyrene, but likely also involves lower-molecular weight species including pyrene and phenanthrene, which have received limited attention in toxicology due to low mutagenic activity. Finally, the implications of this will be discussed in relation to the role of mass versus size or surface area as metrics for combustion particle exposure, and whether there actually is a need to regulate ultrafine particles.

The talk is based previous and ongoing studies from our lab and others, including work from the ULTRHAS-project (Ultrafine particles from inflammation - health assessment of sources) funded under the EU's Research and Innovation program Horizon 2020 (Grant Agreement No. 955390; www.ultrhas.eu).

27th ETH Nanoparticles Conference June 10-14, 2024, ETH Zurich
Topic: Toxicology

Traffic-related non-exhaust emission UFPs toxicological potentials

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BACKGROUND: Traffic-related non-exhaust emissions (NEE) include ultrafine particles (UFPs) generated from vehicle brake wear and railway catenary systems, among others. NEE account for a substantial portion of particle matter (PM) emission from transportation, and therefore pose severe risks to human health. Brake wear contributes significantly to the release of NEE PM, but its characteristics and related toxicological potential may vary depending on the material formulation used, including metals. Like rail catenary sparking contributing to PM fractions with high metal content UFPs. As the nature of origin shape aerosol characteristics and hazard to human health a deeper understanding of toxicologic effects of NEE PM is needed.

METHODOLOGY: For this reason, we investigated the toxicological effects of relevant PM from brake wear and catenary sparking in a controlled laboratory environment. An automated brake dynamometer running a Worldwide Harmonized Light-Duty Vehicles Test Procedure (WLTP) was used to generate PM emissions from a non-asbestos organic (NAO) and a low-metallic (LM) brake pad. A spark discharge aerosol generator was applied to model copper containing UFPs emitted from catenary sparking. Two different lung cell models, a monoculture (MC) of A549 alveolar epithelial cells and a co-culture (CC) system consisting of Calu-3 bronchial epithelial cells, THP-1 differentiated M0 macrophages and EA.hy926 vascular endothelial cells were exposed to these aerosols at the air-liquid interface.

RESULTS: Dose-response assessments for NEE UFPs effects on cellular metabolic activity, barrier integrity and cytotoxicity, were performed. Brake wear and catenary sparking copper particles induced mild cytotoxicity, as measured by the release of lactate dehydrogenase. NAO-pad particles induced a decrease in metabolic activity in the CC system. Copper UFPs induced a less pregnant decrease of metabolic activity, whereas LM-pad particles did not affect metabolic activity. Epithelial barrier integrity was compromised by NAO-particles and copper UFPs, while LM particles did not weaken the epithelial layer. Further investigations will be conducted to determine biomarkers of pro-inflammatory activation and oxidative stress, as previous studies have linked brake wear emission to these events, accompanied by comprehensive genotoxicity, transcriptomic, and proteomic analysis.

This work was supported by the ULTRHAS project funded under the EU´s Research and Innovation programme Horizon 2020 (Grant agreement No. 955390).

On-site ALI versus Submerged Culture: Toxicological and Chemical Investigation of Brake Wear Nanoparticles

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Poor air quality represents one of the biggest risk, both for the human health and for the environment. It has been proven, that polluted air has a direct correlation with respiratory diseases and, in the worst cases, can lead to premature death [1]. Specifically, nanoparticles present in the atmosphere play an important role in determining hazardous effects on human health. Generally, environmental particulate matter originates from various sources, including e.g. non-exhaust PMs (particulate matters) from road transport, which contributes to the progressive worsening of air quality [2].

In this work, toxicological response of A549 cell line (lung epithelial adenocarcinoma cells) was evaluated, both in submerged and on-site ALI (Air-Liquid Interface) conditions. These two systems were exposed to nanometric PMs (<450 nm) resulting from wear process of car brakes. Toxicity was assessed via two different toxicity tests; cell viability (Alamar Blue) and cytokine assays.

The nanoparticle emissions were collected using dynamometric bench, a set-up that simulates standard driving and braking conditions. For submerged condition, nanoparticles were collected on filters, detached and subsequently exposed to cells. Considering ALI conditions, a mobile ALI system was directly connected to the dynamometric bench and freshly emitted nanoparticles were directly exposed onto the cells. For both sampling campaigns, the WLTP (Worldwide harmonized Light vehicle Test Procedure) cycle was used. In this study, two friction materials were examined, labeled as M1a and M1b, both falling into the category of friction couples composed by grey-cast-iron brake discs and ECE R90 Low Metallic brake pads, but with different behavior in terms of chemical composition and braking performance. The morphology and chemical composition of emitted nanoparticles were evaluated through SEM/EDS and Raman Spectroscopy measurements.

A reduction in the cell viability was observed only with the M1a material and only in ALI condition. Further research is needed to understand better the differences obtained between two materials.

Acknowledgments

This research was supported by the European Commision's Horizon 2020 research and innovation programme: nPETS (grant agreement No 954377, https://www.npets-project.eu)

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27th ETH Nanoparticles Conference June 10-14, 2024, ETH Zurich
Conference Topic: *Toxicology*

Genotoxicity of Organic Extracts of Particulate Emissions from Conventional Gasoline and Alternative Fuels

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Introduction: Modern gasoline engines represent an important source of potentially harmful emissions composed of various pollutants including particulate matter (PM). The type of fuel affects both the amount and the toxicity of the emissions. Alternative fuels containing bio-additives have recently become popular as alternatives to non-renewable fossil fuels. However, little is known about the genotoxicity of their emissions. The aim of this study was to compare genotoxic potencies and mechanisms of the potential genotoxicity of organic extracts from gasoline particulate emissions produced by neat gasoline fuel (E0) and its blends with 15% ethanol (E15), 25% n-butanol (n-But25), and 25% isobutanol (i-But25). **Methods:** Human bronchial epithelial cells (BEAS-2B) were exposed to the organic extracts from PM in non-cytotoxic concentrations (1-50 μg/mL) determined by the WST-1 test. The biomarkers of genotoxicity, such as DNA damage evaluated by the comet assay, the micronuclei formation, levels of phosphorylated histone H2AX (γH2AX), and the expression of genes relevant to the DNA damage response, were determined. **Results:** Chemical analysis revealed that despite the lowest PM mass, n-But25 extract contained the highest concentrations of polycyclic aromatic hydrocarbons (PAHs), as well as oxy-, nitro-, and dinitro-PAHs derivates, while in i-But25 extract these concentrations were the lowest. The Comet assay showed that E0 extract generated a significant dose-dependent increase of DNA strand breaks and oxidative DNA lesions. A lower, yet considerable, level of DNA damage was elicited by E15 extract. n-But25 and i-But25 extracts were the least genotoxic; only a mild increase of oxidative DNA damage was observed. The level of γH2AX, indicating DNA double-strand breaks, was not significantly elevated in any sample. The frequency of micronuclei, a marker of genotoxicity and genomic instability, was not affected by any of the tested PM extracts either; the highest doses of all extracts rather decreased the cytokinesis-blocked proliferative index indicating the increasing cytotoxicity or cell cycle delay. Gene expression analysis revealed mild activation of genes related to DNA damage response and strongly increased expression of genes indicating the activation of aryl hydrocarbon receptor (AhR), a nuclear receptor known to mediate toxic effects of PAHs. **Conclusion**: Taken together, the data suggest that PM extracts from diverse conventional and alternative gasoline fuels differ in the qualitative and quantitative chemical composition and that the genotoxic properties in BEAS-2B cells are most likely influenced by the relative proportion of individual PAHs rather than their overall content. AhR activation may play an important role in the toxicity of gasoline PM emissions.

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Trends in exhaust and non-exhaust particle emissions in road transport

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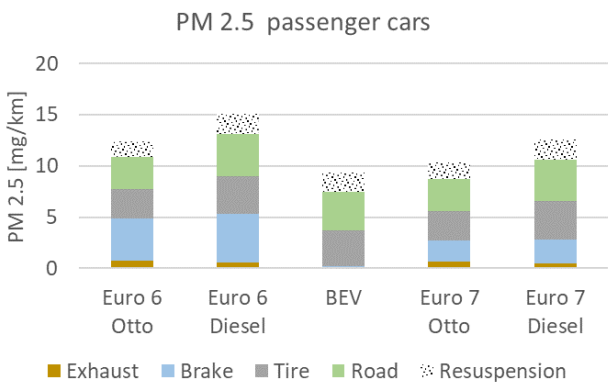
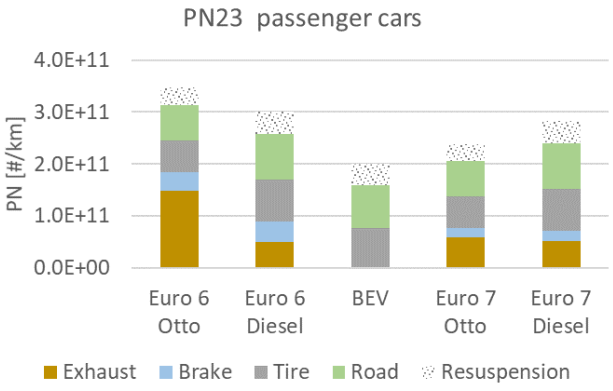
The low particle exhaust emissions from modern vehicles lead to increasing importance of tire-, brake and road wear as well as re-suspended particle emissions, [1]. To meet future EU air quality limits and the even more demanding WHO targets for PM 2.5, reductions in the non-exhaust particle emissions (NEP) seem to be necessary, [2]. Consequently, the EURO 7 emission regulation foresees limits for PM and PN emissions from brake and tire wear. TU Graz is working on test methods, simulation tools and the assessment of reduction technologies for NEP in course of the next update of the HBEFA (Handbook on Emission Factors, www.hbefa.net) and in some research projects with several partners.

In the presentation, we will show results of measurement and data collection campaigns for NEP and for exhaust PN and PM, which are used to parametrise the vehicle emission model PHEM from TU Graz. PHEM is calculating all emission factors for the HBEFA using equations of longitudinal dynamics and load dependent maps for emissions from combustion, tire and brake wear. Effects of brake energy recuperation from hybrid and battery electric vehicles as well as from retarder use in HDVs are considered. The physical approach allows the simulation of all propulsion systems in any driving cycles. The current data in the model shows e.g. for EURO 6d new passenger car fleets some 4 to 6% share of exhaust in PM2.5 and 17% to 43% for PN23. The diesel cars have lower exhaust emissions but are on average much heavier than the gasoline fleet (1700 kg vs. 1250 kg) and thus have higher NEP emissions. However, results indicate, that even pure electric vehicle fleets will not show significantly lower total PM emissions than gasoline and diesel vehicles. Thus, further reduction targets have to include also NEP emissions.





Using the emission factors computed with PHEM as input for an EU 27 road traffic emission inventory model developed in the H 2020 project LONGRUN, we will show PM and PN emission results for Europe LDV and HDV traffic up to 2050 with different technology scenarios.

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Comprehensive investigation on the effect of different brake profiles and temperature on the brake wear particle emissions

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In the last years, particulate matter (PM) emissions from the vehicles have been correlated to the engine exhaust. However, in recent years, the use of even more efficient after-treatment systems and of low/free-carbon fuels as well as the wide spreading of the hybridization of the vehicles have driven down the particle emissions from the internal combustion engines giving more importance to other PM vehicle sources such as the brake and tyre wear debris.
Particles emitted from exhaust (EP) are localized and can be easily collected through a dilution tunnel connected to a sampling system. On the other hand, the measure of brake and tyre wear particles, known as non-exhaust particles (NEP) is more complex since the pathways by which the particles reach the environment are more extended.
Several numerical and experimental studies have been carried out on NEP. Anyway, the results reported in the literature are not consistent and are often difficult to compare because of the different test methodologies, measurement techniques and sampling procedures. In addition, the driving conditions also have a great influence on the extent and characteristics of brake particles.
With regards to the brake particles, they are mainly due to abrasion processes occurring during typical driving conditions and resulting in micron size particles. Moreover, in strong braking conditions, the rising of temperature can pyrolytically generate sub-micron particles.
The aim of this study is to evaluate the effect of different brake profiles and the temperature on the particle number and size. The investigation was performed on a commercial brake typically mounted on light-duty vehicles to which a braking torque has been applied according to a speed profile typical of urban driving conditions. Test were carried out with two different layouts. An open system was realized to simulate conditions as similar as possible to the real ones. A box that contains the brake was also designed to reduce the dispersion of particles in the environment thus improving the reproducibility of the measurements. An EEPS and an OPS were used to measure the particles in the size range from 5.6 nm to 10 µm. The disk temperature was measured by means of an InfraRed camera. The results highlighted that the brake wear particles range between 30 nm and 10 µm. They show a bimodal distribution with a first peak at around 30 nm and a second one at 200 nm. The particle concentration is affected by the brake profile, stronger the braking event, higher the particle emissions. Analogously, the particle number increase with the temperature. No significant difference in the particle size were instead observed between the different test conditions.

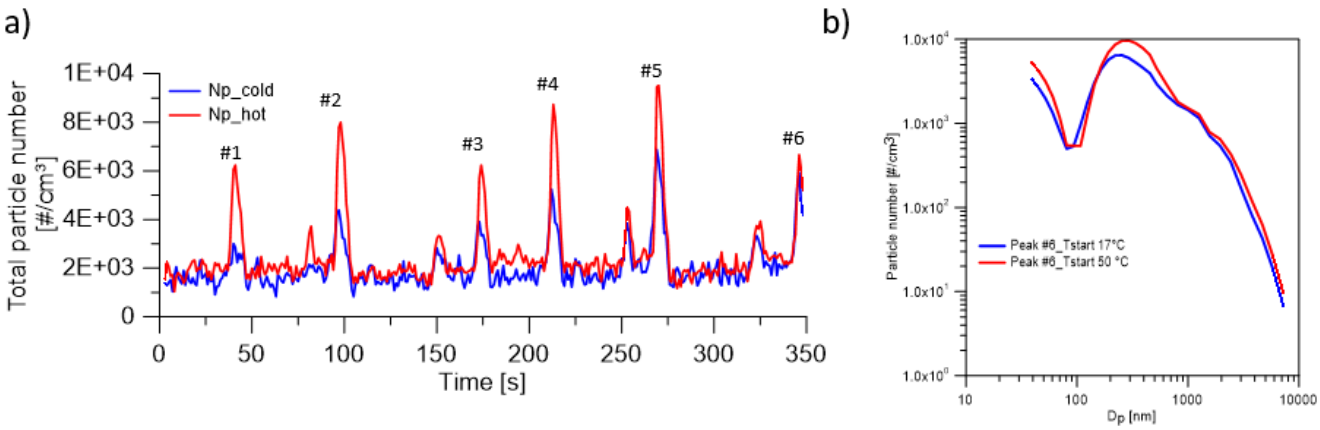

Figure 1.a) Prticle concentration and b) PSD due to the brake wear at two different disk temperatures.

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Implications of Nanoparticle Emissions from Passenger Car Brakes based on the WLTP Brake Cycle

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Brake wear particle emissions are typically associated with vehicle traffic. We determined brake friction works and brake wear particle emissions under realistic vehicle driving and braking conditions using currently used brake systems. We used commercially available brake systems and performed regression analysis between brake friction works and PM_{10}, $PM_{2.5}$, SPN (Solid Particle Number), TPN (Total Particle Number) [1]. Nanoparticle PM (Particle Mass) emissions tended to increase slightly with lower brake friction works, however, they did not contribute significantly to the overall PM percentage. We found that the phenomenon of emission of high concentrations of nuclei mode particles (<20 nm in diameter) occurred under high temperature and high brake friction work conditions (Figure 1). We found that PN has a different emission behaviour compared to PM, suggesting that the nuclei mode particles are generated from gases emitted by combustion or evaporation of the brake friction materials.

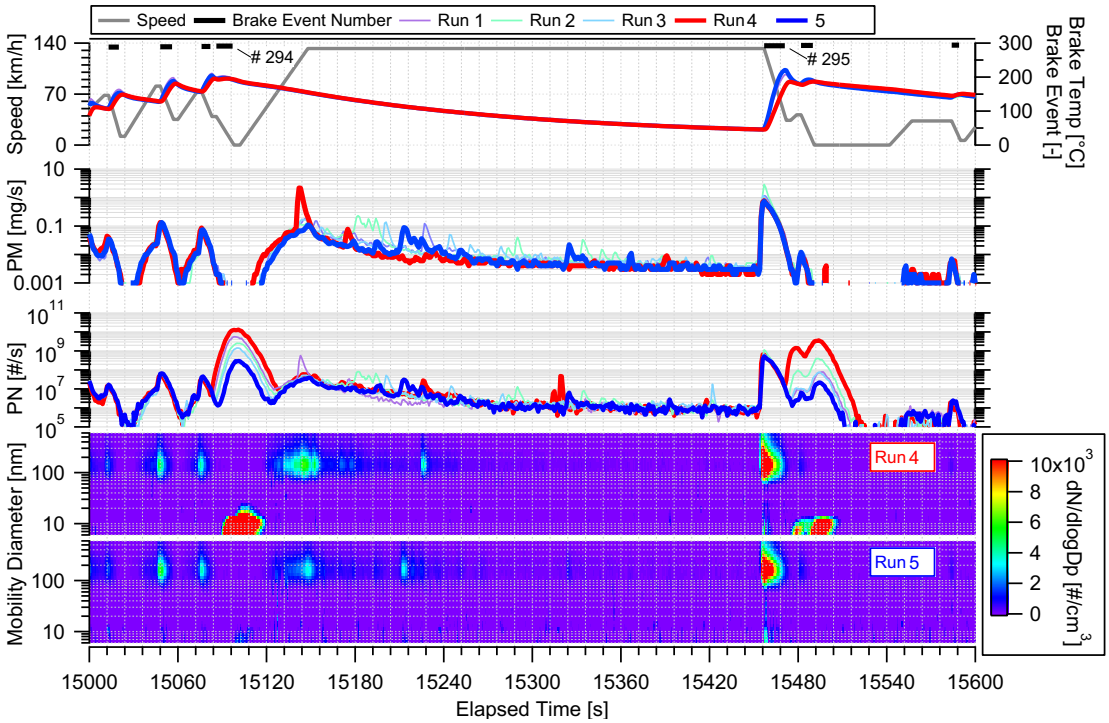

Figure 1 Comparison of speed, brake temperature, PM_{10}, TPN, and distributions of numbers of airborne particle sizes measured in Runs 4 and 5 in FMPS during brake events #294 (15,086 s) and #295 (15,457 s) of the WLTP-Brake Cycle (Data Source : PM data added by author to reference [1]).

Acknowledgments: This work was supported by the Japan Society for the Promotion of Science (JSPS) KAKENHI Grant Number JP 22K03895.The author would like to thank co-workers who supported the set-up and operation of the dynamometer and the measurements.

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Morphology, elemental composition, and nanostructure of brake particle emissions.

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Despite action to shift to less polluting forms of transport, e.g. electrifying passenger cars, all modes of transport still produce the smallest particles from sources including non-exhaust emissions (NEEs) from tyre and brake wear. Metals and organic constituents (PAHs) of wear particles have been reported in the ultrafine region (15-50 nm), although roughly 50% become airborne. The focus on NEEs must be directed to achieve a better understanding on particle formation mechanisms, particle characteristics including size, morphology, composition addressing the content of metals and organic constituents such as PAH species, the design of particle intervention/abatement systems and the impact of particles on human health.

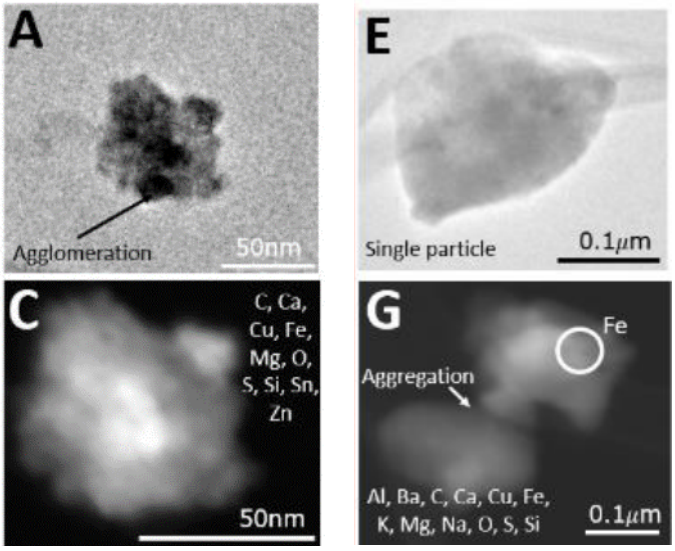

Figure1: Examples of TEM images of ultrafine PM collected from the automotive filter (A,C) and rail Brake wear PM (E,G)

In this work, the morphology and elemental composition of automotive and rail brake PM are compared using Transmission electron microscopy (TEM) and Energy-dispersive X-ray (EDX). The TEM images were obtained using a JEOL 2100F TEM equipped with a Gatan Orius CCD camera, from the Nanoscale and Microscale Research Centre (nmRC) at the University of Nottingham.

Automotive brake PM was collected on filters during Worldwide Harmonized Light Vehicles Test Procedure (WLTP); while the Rail brake PM was collected on filters from a train operated under urban braking conditions. The maximum peak braking temperatures recorded was 150°C. Before being placed on TEM grids, the brake PM samples were sonicated for 15 minutes and then distributed in acetone to prepare them for TEM imaging. The technique used for TEM preparation demonstrated that acetone dispersed brake PM more effectively than heptane, and the procedure produced reliable results.

Both samples exhibited PM in the coarse fine and ultrafine size range. For automotive PM, angular flakes were primarily found in the coarse size range, most likely as a result of abrasion-induced friction wear. Rounded, smooth PM particles were primarily found in the fine and ultrafine size ranges in both samples, most likely formed by friction wear via oxidation. All samples' brake PM chemical composition matches the components of their individual brake discs and pads.

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Physical and chemical characterization of emissions from a EURO 7 brake dyno

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Automotive non-exhaust emissions, such as brake- and tyre wear are of rising interest, since they will be regulated for the first time with the EURO 7 regulation. While the majority of the particle mass of these abrasion derived particles is between 1 and 10 µm, a considerable percentage of the particle number is also generated in the nanoparticle range [1]. These particles can penetrate deep into the lungs, where they deposit in the alveoli and eventually reach the bloodstream via the blood-air barrier [2].

In this study the chemical and physical properties of brake wear particles emitted from a newly developed EURO 7 compliant brake dyno were characterized. Non asbestos organic brake pads (NAO), as well as so called low metallic brake pads (LM), were compared regarding emitted particle mass (PM), particle numbers (PN), as well as their size and morphology utilizing the WLTP bake cycle. Exemplary particle number concentrations of particles < 2.5 µm during a WLTP cycle are plotted in figure 1.

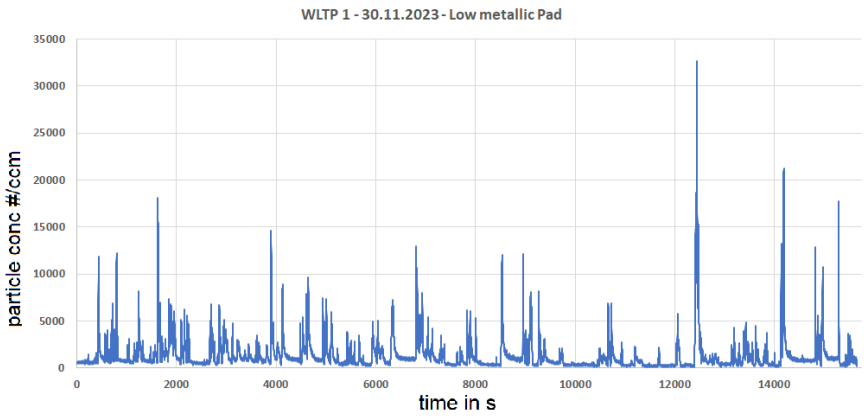

Figure 1: Particle number concentrations of Particle < 2.5 µm emitted by a LM brake pad during a WLTP cycle

Figure 2 depicts a typical SEM micrograph of brake nanoparticle, showing rough edges commonly found for abrasion derived particles. ICP-MS was used for bulk analysis of heavy metals, in combination with SEM-EDX for individual elemental particle spectra, to give a broader understanding of the highly metallic nature of brake wear derived particles.

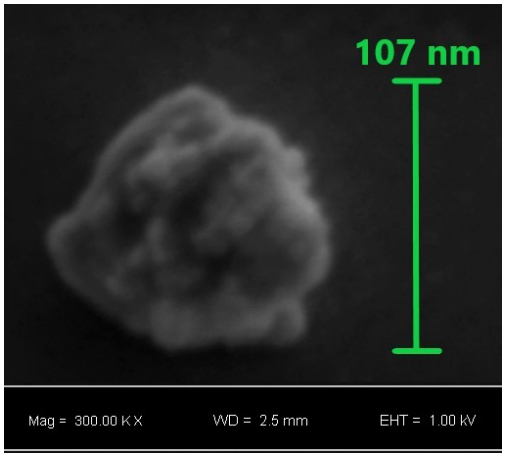

Figure 2: SEM micrograph of a brake wear particle emitted from a NAO brake pad

Furthermore, filters wear extracted and analysed for polycyclic aromatic hydrocarbons by GC-MS/MS to see if high local temperatures leads to generation of such carcinogenic substances at the brake interface due to thermal degradation of the polymer binding matrix of the brake pads.

[1] T. Grigoratos and G. Martini, Environmental Science and Pollution Research International, **2015** 22(4), 2491–2504.
[2] G. Bachler et al., *Particle and Fibre Toxicology*, **2015**, *12(1)*, 18.

Enhancing total carbon quantification using fast-thermograms

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Carbonaceous aerosols (CA) are an important component of the atmosphere impacting climate and health. They comprise a wide range of substances with a continuum of properties (thermal, optical, etc.) and various degrees of toxicity. This has created the desire to split the totality of CA into fractions to better understand their impact and the dynamic of atmospheric processes, including the formation of secondary organic aerosols. Traditional methods like thermal-optical analysis (TOA) separate particle-bound total carbon (TC) into organic (OC) and elemental carbon (EC), while optical techniques focus on diverse black carbon fractions (eBC and rBC). Despite the important data generated by these methods, a major challenge persists: the operational definition of fractions based on sample behaviour during analysis, rather than on a clearly defined material composition. This leads to potential artifacts in mass quantification and an unclear equivalence among different fractions.

Our study introduces a novel approach utilizing total carbon (TC) measurement, a reliable and robust parameter, enhanced with fast thermograms produced by our FATCAT measurement system [1]. The new measuring device allows autonomous, continuous operation over several months in, for example, air hygiene measuring stations and has a detection limit of 0.2 µg/m^3 TC. Unlike traditional thermograms produced by, e.g., TOA, fast thermograms provide insights into volatility and refractoriness without imposing an artificial separation into fractions or a thermal protocol. Laboratory tests demonstrate identifiable patterns for different primary and secondary organic matters or different soot types. Additionally, ambient measurements from diverse locations using FATCAT highlight the influence of various sources on thermogram patterns. This method offers a straightforward yet robust tool for carbonaceous aerosol analysis, which can be used for source apportionment and understanding fundamental sample properties.

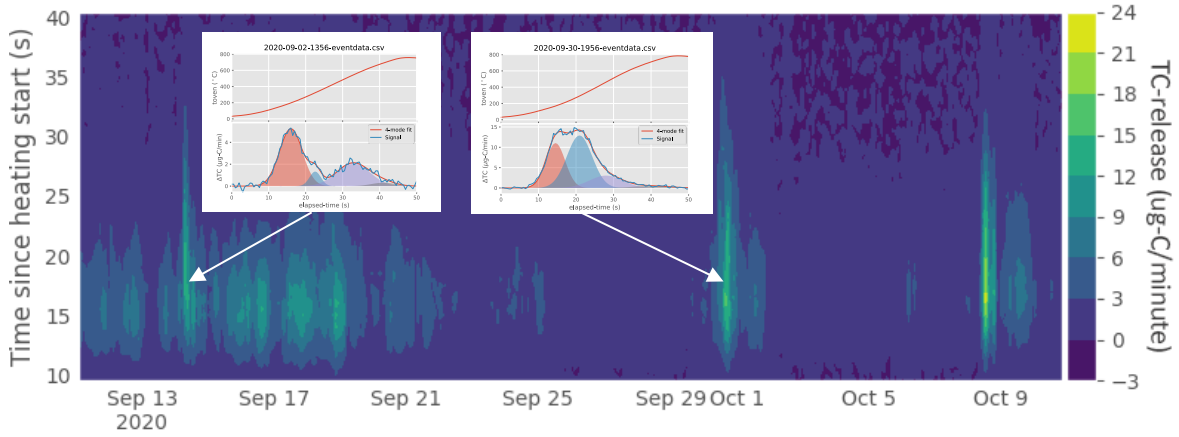

Figure: Contour plot of thermograms from one month of unattended FATCAT measurement at the Jungfraujoch GAW Global monitoring site. The color scale represents the rate of release of carbon from the sample during analysis. The insets show the detail of thermograms corresponding to local fossil fuel emissions (left) and intercontinental transport of biomass burning emissions (right) events.

[1] A. Keller, P. Specht, P. Steigmeier, E. Weingartner, *Aerosol Research*, **2023**, 1, 65–79.

Quantitative Measurement of Dynamic Changes of Trace Element Content in Ambient Aerosol by MICAP-TOFMS

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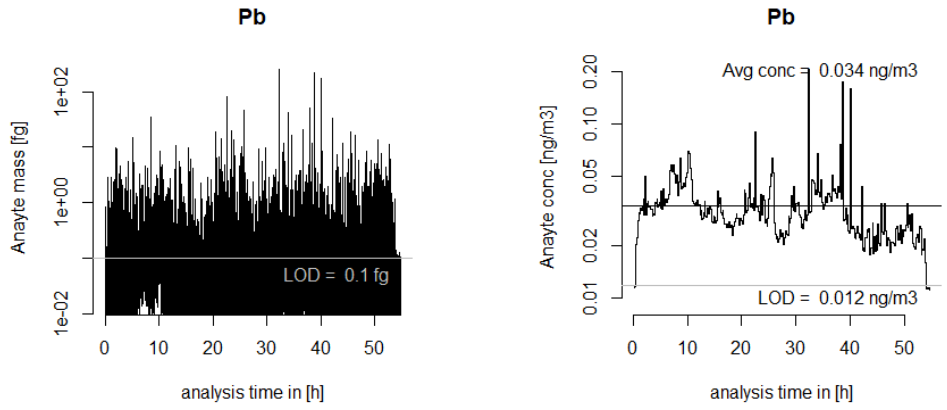
Knowledge of metal content in aerosol is crucial for source apportionment and estimation of potential health risks [1]. However, quantification of metal aerosols is analytically challenging because low detection limits for a wide range of analytes are required. Currently, there are two main technologies applied: ICP-MS [1] and XRF [2]. Both ICP-MS and XRF are typically used to analyze aerosol that is collected on filters, and so can only provide metal-aerosol content with a time resolution from 30 minutes to 24 hours. Nonetheless, shorter accumulation times (or even real-time analysis) would be preferable to allow for monitoring dynamic processes of variable metal concentrations in outdoor or indoor environments.



Pb content in industrial indoor air. Signal measured in 1 s intervals over 50 h (left). The same signal averaged to 10 min intervals and considering the actual volume flow (right).

We present an approach to directly measure aerosol metal content at the single-particle level and in real time using a Microwave-Sustained, Inductively Coupled, Atmospheric-pressure Plasma (MICAP) coupled with a Time-of-Flight Mass Spectrometer (TOFMS) [3]. Microdroplet calibration standards were used to calibrate signal intensities to analyte mass [4]. The setup offers simultaneous detection of femtogram amounts of most metallic elements in individual particles, which translates to ng m^{-3} detection limits. Results from measured indoor and outdoor air will be discussed.

[1] Daellenbach, K. R., Uzu, G., Jiang, J., Cassagnes, L. E., Leni, Z., Vlachou, A., Stefenelli G., Canonaco F., Weber S., Segers A., Kuenen J. J. P., Schaap M., Favez O., Albinet A., Aksoyoglu S., Dommen J., Baltensperger U., Geiser M., El Haddad I., Jaffrezo J.-L. & Prévôt, A. S., *Nature*, **2020**, 587(7834), 414-419.

[2] Furger, M., Minguillón, M. C., Yadav, V., Slowik, J. G., Hüglin, C., Fröhlich, R., Petterson, K., Baltensperger, U., and Prévôt, A. S. H., *Atmos. Meas. Tech.*, **2027**, 10, 2061–2076

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[4] Hendriks, L., Ramkorun-Schmidt, B., Gundlach-Graham, A., Koch, J., Grass, R. N., Jakubowski, N., & Günther, D., *Journal of Analytical Atomic Spectrometry*, **2019**, 34(4), 716-728.

A new kind of substance for the rapid activation and heterogenous growth of nanoparticles in particle counters

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Aerosols containing nanoparticles below a certain size cannot be measured easily. A Condensation Particle Counter (CPC) is one of the most important measuring instruments used in aerosol science because it makes the particle counting process essentially size independent. The CPC operates by evaporating a working fluid through heating and cooling, causing it to condense onto the particles. This condensation process results in significant particle growth, allowing for detection through an optical measurement cell. The working fluid is a crucial component of any CPC instrument. Ideally, it should have low consumption and not be toxic or harmful to the environment. Previous research has shown that dimethylsulfoxide (DMSO) can be used as a working fluid in alcohol-based CPCs with only minor modifications (Weber et al., 2023). DMSO is a naturally occurring and sustainable substance that poses no hazards. The initial scientific characterization of DMSO as a new working fluid in alcohol-based CPCs was conducted.

In our experimental study, we used a differential mobility analyser (model M-DMA 55-U, Grimm Aerosol Technik, Ainring, Germany) to select monodisperse particle sizes. We also used an electrometer (model 5.705, Grimm Aerosol Technik) as a reference instrument for particle number concentration. The experimental set-up included various mass flow controllers to adjust the in-line pressure using a PID approach. The substance's behaviour as a working fluid in a CPC was characterised for operating pressures ranging from ambient pressure down to 200 hPa. Additionally, the counting efficiency and the D50 cut-off diameter were analysed in detail under different measurement conditions.

Additionally, we will introduce a new substance for the rapid activation and heterogeneous growth of nanoparticles that has not been previously used in particle counting instruments. This new substance introduces a new form of particle growth principle. We will confirm our new finding by conducting an initial analysis of its applicability and examining its characteristics, including the lower cut-off diameter and overall instrument response, which are similar to those of DMSO.

This research has been supported by the Bundesministerium für Bildung und Forschung (grant no. 01LK1301A) and the Forschungszentrum Jülich (HITEC).

Weber, P., Bischof, O. F., Fischer, B., Berg, M., Schmitt, J., Steiner, G., Keck, L., Petzold, A., and Bundke, U. (2023). A new working fluid for condensation particle counters for use in sensitive working environments, Aerosol Research, 1, 1–12, https://doi.org/10.5194/ar-1-1-2023

Accurate retrieval of pure black carbon aerosol properties including light absorption from polarization-resolved in situ measurements of light scattering

Q.-Z. Xu[1], B. Bertozzi[1], R. L. Modini[1], B.T. Brem[1], and M. Gysel-Beer[1]

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Probing angular and polarization dependence of light scattering together with polarimetric retrievals play a crucial role in remote sensing of aerosol size distribution and light absorption. In particular, accurate retrieval absorption by black carbon remains a main challenge, as demonstrated by Schuster et al. (2019) in controlled laboratory experiments, partly due to simplified aerosol representation in standard retrieval algorithms. Here we demonstrate that considering non-spherical shape reduces uncertainty and bias of aerosol property retrievals for BC particles.

We used PSL (spherical, non-absorbing), nigrosin (spherical, absorbing) and surrogates of black carbon particles (non-spherical aggregates, absorbing) as test aerosols. An Aerodynamic Aerosol Classifier was used to produce unimodal size distributions. Phase function and polarized phase function were measured using a laser imaging type nephelometer (Moallemi et al., 2023). Aerosol properties were independently measured using a condensation particle counter, scanning mobility particle sizer, aerosol particle mass analyzer, and photo-acoustic absorption photometer.

Optical forward calculations were either done using Mie theory for spheres or using Multi-Sphere T-Matrix (MSTM) calculations for BC surrogates. Property retrievals were done by fitting the measured phase function data using above forward kernel and aerosol properties as fit parameters.

For spherical homogeneous particles (PSL and nigrosin), agreement with independent data was excellent with RMSE of around ±1.95% for modal diameter, ±7.99% for number concentration. Retrieval of complex refractive index was also in good agreement with literature data with RMSE of ±0.02 for real part and ±0.04 for imaginary part. A RMSE of ±6.13% achieved for the absorption coefficient also falls within uncertainty of the independent measurement.

While using Mie kernel does not yield a satisfactory match to phase functions measured for non-spherical BC aggregates (blue line in Fig. 1) leading to systematic biases in retrieved aerosol parameters. In contrast, using the MSTM kernel provided a good fit (red lines in Fig. 1) and resulted in unbiased retrieval of aerosol properties including absorption within uncertainty. Future work will focus on coated BC and on ambient samples to assess the potential of reducing retrieval uncertainty for atmospheric aerosol by including a BC particle component in the aerosol model and optical forward kernel.

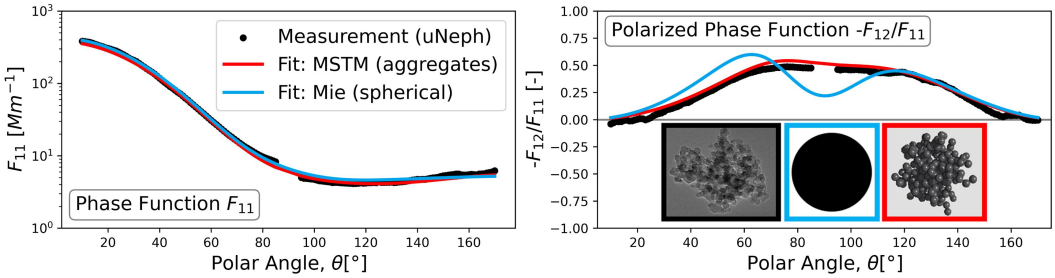

Fig. 1 Measured and fitted phase functions for size-selected pure BC with an aggregate shape.

The results demonstrate that a simple aggregate model (monodisperse primary spheres) is sufficient for accurate BC property retrieval given simple BC aerosol samples.

[1] Moallemi, A., *et al. Atmos. Meas. Tech.*, **2023**, 16, 3653-3678.
[2] Schuster, G. L., Espinosa, W. R., *et al. Remote Sens.*, **2019**, 11, 498

Accurate retrieval of pure black carbon aerosol properties including light absorption from polarization-resolved in situ measurements of light scattering

Q.-Z. Xu[1], B. Bertozzi[1], R. L. Modini[1], B.T. Brem[1], C. Mohr[1], B. Romshoo[2], T. Müller[2] and M. Gysel-Beer[1]

[1]Laboratory of Atmospheric Chemistry, Paul Scherrer Institute, Villigen PSI, 5232, Switzerland
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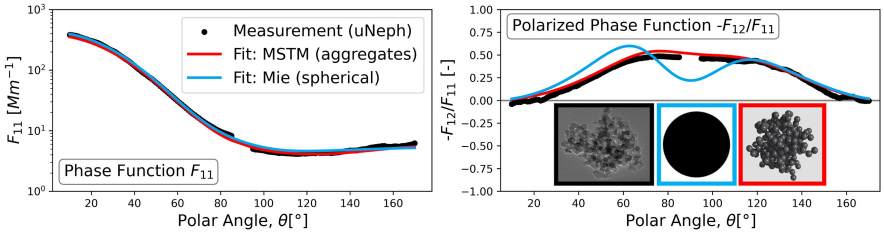

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[2] Schuster, G. L., Espinosa, W. R., *et al. Remote Sens.*, **2019**, 11, 498

Assessing particulate matter emissions from conventional cigarettes and heated tobacco products

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In quantifying solid particle emissions from Internal Combustion Engines, a spectrum of methodologies has been advanced for distinguishing solid particles from volatile and semi-volatile compounds. Previous research [1] introduced a novel Volatile Particle Removal (VPR) system, incorporating an advanced Catalytic Stripper (CS) capable of oxidising volatile hydrocarbons and sequestering sulfur species. This system underwent adaptation and optimisation to facilitate the assessment of whether solid particles are present in the emissions from combustible conventional cigarettes (CCs) and heated tobacco products, specifically the IQOS products developed by Philip Morris International.

The study analysed particulate matter emissions generated by reference (1R6F) conventional cigarettes and IQOS products (ILUMA and DUO) using a Programmable Single Syringe Pump (PSSP), comparing scenarios with and without the VPR system. Particle number concentration was monitored using a Condensation Particle Counter (CPC), while particle size distributions were determined with a Scanning Mobility Particle Sizer (SMPS) and an Engine Exhaust Particle Sizer (EEPS). Inline compositional analysis of the emitted particulates was also performed with a Time-of-Flight Aerosol Chemical Speciation Monitor (ToF-ACSM).

The VPR system was used to eliminate volatile particulate matter exhibited remarkable efficiency i.e. tetracontane and glycerine particles were removed at rates exceeding 99.990% and 99.999%, respectively. The penetration efficiency of solid particles was also evaluated using monodisperse and polydisperse particles. Average penetration rates exceeded 80% for particles larger than 10 nm, with penetration for 10 nm particles surpassing 50%. Notably, penetration efficiency appeared invariant for particles larger than 20 nm.

It was observed that aerosol generated by IQOS devices markedly surpassed conventional cigarettes in terms of reduced particle emissions. The total (solid or droplets) particle number emitted per unit (stick or cigarette) was significantly higher for CCs compared to IQOS by four orders of magnitude. The IQOS devices emitted larger particulate matter (droplets), predominantly in the range from 100 to 150 nm, in contrast to the majority of CC particles, which ranged from 30 to 100 nm, with an additional peak around 250 nm. Particulate matter emissions from both sources predominantly consisted of volatile species. The VPR system with IQOS products almost eliminated particle counts of the particulate matter in the IQOS emissions. The downstream of the VPR emissions from CCs remained significantly high, verifying the existence of solid particles in the CCs case. Particle sizing for those solid particles revealed two distinct peaks: an initial peak at 10 nm for nuclei-mode particles and a second peak at 100 nm, indicative of aggregated particles.

Significant disparities were also identified in the composition of particulate matter emitted from IQOS products and conventional cigarettes. Without the VPR, concentrations of organic compounds were comparably high across all tests, exhibiting similar magnitudes. However, CC emissions contained organic compounds with lower oxygen content compared to those from IQOS products. Sulphate concentrations in CC smoke were an order of magnitude higher than in IQOS emissions. Additionally, CC smoke exhibited a notably higher prevalence of nitrates, approximately three times that in IQOS emissions, and chloride concentrations in CC smoke were about 30 times greater than in IQOS emissions. In the presence of the VPR, concentrations of these compounds in IQOS emissions were negligible, well below the instrument's detection limit. For CCs, even post-catalytic stripping, certain organic compounds and chlorides persisted.

In conclusion, this study's detailed analysis of particulate matter revealed that emissions from IQOS consist of volatile particulate matter (droplets), whereas conventional cigarette (CC) emissions contain both volatile and solid particles. The data showed no indication of soot particles in IQOS emissions, unlike cigarette smoke, which contains a high concentration of soot particles.

[1] A. D. Melas, V. Koidi, D. Deloglou, E. Daskalos, D. Zarvalis, E. Papaioannou & A. G. Konstandopoulos, *Aerosol Science and Technology*, **2020**, *54:6*, 704-717, DOI: 10.1080/02786826.2020.1718061

27th ETH Nanoparticles Conference June 10-14, 2024, ETH Zurich
Conference Topic: *Ambient air & soot particles, secondary pollutants*

Nanoparticle and contrail ice formation in next generation aviation fuels and engines

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Currently, there is an urgent need to understand contrail formation from developmental aviation fuels (sustainable aviation fuels (SAF) and liquid hydrogen (LH2)) and lean burn combustion technologies. The value proposition of next generation aviation fuels is primarily from realizing net reduced or zero levels of CO_2 emission. The value proposition for lean burn combustion technologies includes not only higher engine efficiency, but substantially lower values of soot emission levels. There is confidence that these stated benefits can be realized. However, a substantial risk relates to the climate impact from non-CO_2 emissions – namely, an increase in contrail formation from these could substantially reduce the benefits of CO_2 mitigation. This aspect has been studied by Kärcher and Yu (2009), where they have pointed out that at orders of magnitude less soot conditions, other aerosols can contribute towards contrails, especially volatile nanoparticles formed in the plume. Up until the onset of contrail formation, the concentration and size of the volatile nanoparticles depends on the concentration of H_2SO_4 vapor (and condensable organics) in the plume, and the effects of ionization and mixing process (Yu & Turco, 1997). In a recent publication on the climate impact of aviation emissions (Lee et al., 2023), Lee has pointed out that the areas of low confidence mostly cover novel jet fuels and low soot emitting engines where there is a great need to conduct studies to better understand the formation and potential contribution of volatile nanoparticles to contrail formation.

Here we use use a detailed aerosol and contrail microphysics model (an improved version of the model used in Kärcher and Yu (2009)) to study the formation and controlling parameters of contrails observed during ECLIF (Emission and CLimate Impact of alternative Fuels) campaigns 1-3 (Voigt et al., 2021 and Markl et al., 2023). The model can overall capture the dependence of ice number concentrations on soot emission index, as observed during ECLIF1-3 for aircrafts running on jet-A, jet-A and SAF blended, and 100% SAF. We find that the activation of soot particles during contrail formation is likely determined by the sizes of primary soot particles rather than the effective sizes of aggregates assumed in previous studies of soot activation calculation. The smaller sizes of primary soot particles (compared to the measured aggregates sizes) delay starting time of contrail formation and increase the maximum supersaturation reached in the contrail and thus increase the probability of small volatile nanoparticles to be activated into contrail particles. Conditions favor the formation of volatile nanoparticles and their contributions to contrail ice formation in next generation gas turbine engine fuels and engines will be discussed.

[1] Kärcher, B., & Yu, F., *Geophys. Res. Lett.,* **2009**, 36, https://doi.org/10.1029/2008GL036649.
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[4] Voigt, C., et al., *Commun. Earth Environ.,* **2021**, 2, https://doi.org/10.1038/s43247-021-00174-y.

Impact of biomass burning on Arctic aerosol composition

Yvette Gramlich[1,2], Karolina Siegel[1,3], Sophie L. Haslett[1], Roxana S. Cremer[1], Chris Lunder[4], Snehitha M. Kommula[5], Angela Buchholz[5], Karl Espen Yttri[4], Gang Chen[6], Radovan Krejci[1], Paul Zieger[1], Annele Virtanen[5], Ilona Riipinen[1], and Claudia Mohr[1,2,7]

[1]Department of Environmental Science and Bolin Centre for Climate Research, Stockholm University, Stockholm, Sweden; [2]Laboratory of Atmospheric Chemistry, Paul Scherrer Institute, Villigen, Switzerland; [3]Department of Meteorology, Stockholm University, Stockholm, Sweden; [4]NILU – Norwegian Institute for Air Research, Kjeller, Norway; [5]Department of Technical Physics, University of Eastern Finland, Kuopio, Finland; [6]MRC Centre for Environment and Health, Environmental Research Group, Imperial College London, London, W12 0BZ, UK; [7]Department of Environmental System Science, ETH Zurich, Switzerland
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During the most recent years, fire activity from biomass burning has become more frequent [1]. The emissions from such events contain aerosol particles composed of organic material and black carbon that can be transported to pristine environments, i.e., the Arctic, while undergoing atmospheric aging [2]. The changes in the physicochemical properties during the aging process can have implications for the cloud-forming ability of the particles, and thereby for the climate.

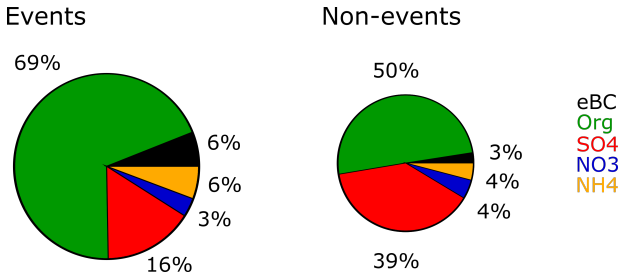

Figure 1: Bulk chemical composition of submicron particles during the biomass burning events (Events) compared to the rest of the year (Non-events), scaled to the total mass concentration.

By using in situ observations in 2020 in Ny-Ålesund, Svalbard, we investigate how the properties of submicron aerosol particles reaching the Arctic change when influenced by biomass burning. We compare the aerosol physical and chemical characteristics between times impacted by biomass burning with the rest of the year and observe a shift from a sulfate- and organic-dominated composition to an organic-dominated composition (Figure 1), resulting in a significantly lower hygroscopicity of the biomass burning aerosol. Signals from biomass burning tracer compounds indicating agricultural and wildfire activity were observed when the air mass passed over fires in Eastern Europe. Our results show that the largest impact on the Arctic aerosol occurs from fires potentially linked to agricultural land burning in Eastern Europe.

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Measurement and impacts of the mass fraction of volatile coatings on soot

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Soot particles entering a high-intensity laser beam (~1 MW/cm^2 at 1064 nm) reach incandescent temperatures prior to vapourization. This laser-induced incandescence is proportional to the mass of refractory black carbon (rBC) in the particle, as exploited for example in the Single Particle Soot Photometer (SP2). This proportionality may be calibrated to rBC mass using thermally denuded, charge-neutralized soot particles classified by a Centrifugal Particle Mass Analyzer (CPMA), as the CPMA transmits only particles of a known mass-to-charge ratio. Subsequently, SP2 measurements of CPMA-classified, possibly coated soot particles directly provides single-particle rBC mass fractions. Inversion of the processed data provides a two-dimensional distribution of the soot coating mass fraction at any given size. In this presentation, we will compare the direct CPMA-SP2 quantification of soot mixing state with previous approaches. We will discuss how this two-dimensional distribution must be considered in order to accurately estimate the direct radiative forcing on climate by atmospheric soot, and address the uncertainties in such estimates.

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Conference Topic: *Ambient air & soot particles, secondary pollutants*

Towards continuous measurement of the oxidative potential of the air

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Whereas PM mass concentration is associated in epidemiological studies to health effects, this indicator may underestimate the overall impact, as often a large amount of low-toxicity compounds contribute to the mass. On the contrary, the presence of tiny amount of toxic or redox active chemical on the surface of PM are not taken into account by such a metric. The measure of oxidative properties - that is the OP - of ambient aerosol appears as a more integrative metric than mass to evaluate their health effect. In contrast to off-line OP measurement approaches based on PM sampling on filters [1], we developed an integrated OP determination device that relies on photonic transducer able to perform on-line OP analysis of the full aerosol: gas and particle phases. The developed OP determination device was deployed at an urban air quality station in the city of Lausanne (Switzerland), to perform measurements during multiple weeks jointly to standard environmental pollutants monitoring such as NOx, ozone, $PM_{2.5}$ and ultrafine particles.

The on-line measurement system is based on a configuration in which i) the air sample is sprayed into clean water as sample collecting medium (flow rate: 2 $Lmin^{-1}$) in order to maximize the air-liquid interface; ii) the water-transferred sample is driven through a series of actuators to the sensing chamber where a reactive solution containing Fe(II) is added; iii) the kinetics of Fe(II) oxidation is followed with photonic measurements using orange LED (580 nm) as probing light, NIR LED as reference (950 nm) and CMOS photodetector as a transducer. Reservoirs for water, reactive and waste enable the OP device to run autonomously for one week without intervention. For on-site measurements the OP device was set in an air quality station located at the vicinity of a construction site and vehicle traffic.

The analytical performances of the photonic detection core as well as the fully automated instrumentation gives rise to a short time-resolution of about 8 min and limit-of-detection below 10 pmol (eq. H_2O_2). The preliminary results obtained from a measurement campaign conducted in winter 2023 at the air quality station clearly indicate that O_3 strongly contributes to the OP, notably more than $PM_{2.5}$. The possibility to perform continuous and long-term OP measurements along with the monitoring of standard air pollutants as well as meteorological conditions will definitively help in refining our understanding of this emerging metric.

This work is supported by the Swiss Federal Office for the Environment who funded the project DIROP (UTF 684.04.22).

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Systematic review on health effects of long-term exposure to UFP

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Background: Due to their small size, ultrafine particles (UFP≤100nm) can reach deeply into the lungs and could exert higher toxicity on the body organs in comparison with fine particulate matter. Within the last 5 years an increasing number of epidemiological studies examined long-term UFP exposure and health effects.

Objectives: We systematically reviewed the literature on health effects of long-term exposure to UFP.

Methods: Epidemiological studies were searched comprehensively in the electronic databases PubMed and LUDOK (the Swiss literature database on air pollution and health) from January 2017 to September 2023. Articles were included after matching the following eligibility criteria: original epidemiologic studies, reported on the general or sub-populations, assessed long-term exposure of UFP measures, investigated clinical or preclinical health outcomes and reported a quantifiable measure of association. Internal validity of studies was evaluated with a risk of bias instrument.

Results: We identified 53 original studies investigating long-term associations. The vast majority were cohort studies (79.2%) conducted on the general population (62.3%). Half (54.7%) were located in western Europe and 37.7% in North America. More than a third of the studies (41.5%) used a land-use regression model (both spatial and spatio-temporal) to assess surrogates of UFP. Thirty studies adjusted for at least one other co-pollutant. Most identified outcomes were cardiometabolic outcomes (43.4%) including diabetes (N=6), hypertension (N=5), stroke (N=4), and myocardial infarction (N=3); respiratory outcomes (13.2%) including asthma (N=5) and pregnancy outcomes (13.2%) including pre-term birth (N=2). We found adverse association between long-term exposure to UFP with cardiometabolic (78.5%), respiratory (42.9%) and pregnancy (50.0%) outcomes.

Conclusion: The evidence on health effects of long-term exposure to UFP is growing rapidly and suggests adverse associations with several outcomes.

Association of ultrafine particle exposure with lung and neuro-cognitive functions in elementary school children in the Berlin-Brandenburg Air Study (BEAR)

Ogurtsova K [1], Soppa V [1], López-Vicente M [2,3,4,5], Guxens M [2,3,4,5], Weinhold K [1], Winkler U [6], Wiedensohler A [6], Held A [7], Lüchtrath S [7], Cyrys J [8], Kecorius S [8], Gastmeier P [9], Wiese-Posselt M [9], Hoffmann B[1].

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Health effects of ambient ultrafine particles (UFP), especially those from aviation sources (AC-UFP), are attracting growing interest, yet limited evidence is available. The Berlin-Brandenburg Air Study (BEAR)[1], a natural experiment, focuses on short-, medium-, and long-term health effects of UFP and AC-UFP on children. The children in the study were attending elementary schools in proximity to the newly opened Berlin-Brandenburg Airport (BER) (opened in October 2020), the former operating Airport Tegel (TXL) (closed in November 2020), and in control areas in Berlin, Germany.

Total particle number concentration (PNC) and meteorological parameters were continuously monitored at 16 elementary schools of participating children using three matching condensation particle counters (CPC) with a 50% cut-size at 7 nm, (EDM 465, Grimm, Germany). To ensure data quality, we implemented a rigorous quality assurance protocol.

Each child underwent repeated (at least two times) school-based health-examinations between January 2020 and June 2023 including spirometry to assess lung function (forced expiratory volume (FEV) and forced vital capacity (FVC) analysed here) and standardized tests to measure neurocognitive function (N-back Test, a parameter hit reaction time (HRT) analysed here, and Attentional Network Task Test). To estimate the association between daily PNC exposure (with lag 0, 1 and 2), as a proxy of UFP, and health outcomes, we employed a nested linear mixed-effect model with random intercepts for school and participant. All models were adjusted to the temperature at the previous day. The results were given by an interquartile range (IQR) increase.

Our findings revealed a discernible decrease in measured PNC with an increase in distance from the airfield, a trend that varied by season and yielded inconclusive results for detecting an airport fingerprint. Within BER airport, a daily average of approximately 16,600 cm^{-3} was measured, and in the vicinity of TXL during high airport activity, it reached approximately 15,400 cm^{-3}—nearly twice as high as the PNC

recorded when the airport remained closed. Median PNC concentrations (6,200 cm^{-3}) across 16 measurement sites throughout the entire study period closely align with reported PNC values observed in other urban environments.

In total, 1,094 children (mean age at baseline 8.6 years, 51% female) were examined. Preliminary analyses of 1,150 complete observations showed a negative association between PNC on the day of the examination and FEV1 (-0.14 litters per each IQR increase of 4,390 particles/cm^3, 95% CI [-0.16; -0.11]) and FVC (-0.17 litres per 4,390 particles/cm^3, 95% CI [-0.20; -0.14]). On lags 1 and 2 the similar associations were detected. HRT was 17.25 ms [95% CI 1.09; 33.41] longer per 4,390 particles/cm^3, measured on the day before the examination, and 19.21 ms [95% CI 2.84; 35.58] longer per 4,390 particles/cm^3, measured two days before the examination. No effect was found for PNC at the day of the examination. After adjusting for area (BER, TLX, CA), the estimates remained unchanged. Also, we didn't find any area-specific effect.

The BEAR Study is a unique experiment investigating effects of AC-UFP, approximated by PNC, on children. The observed associations between measured PNC in proximity to Berlin airports and lung and neurocognitive functions in school-aged children raise concerns about the potential health impact of AC-UFP.

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Nanoparticle profiling: a comprehensive assessment of physical, chemical, and toxicological characteristics at Thessaloniki airport

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Despite the growing attention towards ground-level aircraft emissions and air pollution near airports, numerous research gaps persist [1]. This study focuses on air quality measurements conducted in proximity to runways during take-offs and landings at Thessaloniki Airport, emphasizing particle characteristics in both summer and winter seasons. Employing various instruments, we evaluated particle mass, number, size distribution, and nanoparticle concentration in the air. Chemical analysis, including examination of volatile organic compounds and metal components, was carried out to provide a more thorough understanding of the particulate matter composition. Background measurements served as a reference for comprehensive results. In parallel, Air-Liquid Interface (ALI) tests with human lung cells were performed, shedding light on the toxicological effects of the measured particles on the respiratory system. The results indicate a decrease in cell viability and an increase in cytokine release, contributing valuable information to the assessment of air quality near active runways. This study enhances our comprehension of particle pollution in airport environments, with potential implications for environmental management and regulatory considerations.

Acknowledgments
This research was supported by the European Commision's Horizon 2020 research and innovation programme: nPETS (grant agreement No 954377, https://www.npets-project.eu)

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Airborne Nanoparticle Concentrations are Associated with Brain Cancer Incidence in Canada's Two Largest Cities

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Transportation and industrial activities emit large quantities of nanoparticles (a.k.a. ultrafine particles; particulate matter < 100 nm in diameter) resulting in urban environments with high concentrations of airborne ambient (i.e. outdoor) nanoparticles. There is emerging evidence that long-term exposure to outdoor nanoparticles is associated with adverse health outcomes such as mortality [1] and brain cancer incidence [2], though there are very few studies investigating the latter. The aim of this research was to estimate the association between long-term exposure to outdoor nanoparticles and brain cancer incidence. Newly developed exposure models [3] were used to estimate outdoor nanoparticle concentrations at the residential addresses of a large, population-based cohort in Montreal and Toronto, Canada and this cohort was followed from 2001 – 2016. The associations between long-term exposures to outdoor nanoparticle concentrations and brain cancer incidence were estimated using Cox proportional hazards models. We observed that an increase in long-term exposure to outdoor nanoparticles was associated with an increased risk of brain cancer incidence (Hazard Ratio = 1.183, 95% Confidence Interval = 1.062, 1.320). Furthermore, we observed that this relationship was confounded (i.e. distorted) by nanoparticle size, with larger nanoparticles being more strongly associated with brain cancer incidence than smaller nanoparticles. There are very few known and modifiable risk factors for brain cancer [4] and our results suggest there is great potential to reduce the incidence of this deadly disease.

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Physical and cell toxicity properties of Euro 6d diesel vehicle particle emissions with and without DPF regeneration

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Despite infrequent and short-lasting occurrences, Diesel Particle Filter (DPF) regenerations can significantly influence particle emissions from Euro 6d diesel vehicles [1,2]. This study explores the physical characteristics and toxic effects of particle emissions under Real Driving Emissions (RDE) conditions, shedding light on factors crucial for legislative considerations. Our specific objectives were to assess DPF regeneration frequency and duration and investigate its impact on particulate number (PN) emissions, size distribution and nanoparticle levels along with their toxicological effects. By testing a Euro 6d diesel vehicle on a chassis dyno, including DPF regeneration, we could measure particle emission properties, cytotoxicity, cell viability and stress induction in a cellular model using the Air Liquid Interface method. Results reveal a significant impact of DPF regeneration, with over 95% of the total particle number produced during regeneration events. Preliminary analysis indicates a decrease in cell viability due to regeneration particles.

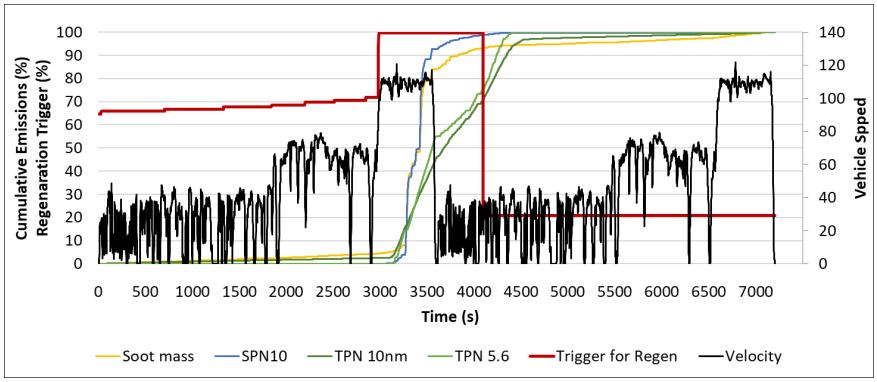

Figure 1 Cumulative particle emissions during regeneration event.

SPN: Solid Particle Number, TPN: Total (solid and volatile) Particle Number

Acknowledgments
This research was supported by the European Commision's Horizon 2020 research and innovation programme: nPETS (grant agreement No 954377, https://www.npets-project.eu)

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Conference Topic: *Indoor Particles*

Influence of ventilation and room air movement on formation and growth of 1-20 nm particles via ozone-human chemistry

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Ozone reaction with human surfaces is an important source of ultrafine particles indoors. Our previous study (Yang et al., 2021) was the first to report nanocluster aerosol (NCA, sub-3 nm particles) formation via ozone reaction with humans. However, 1-20 nm particles generated from ozone-human chemistry, which mark the first step of particle formation and growth, remain understudied. Ventilation and indoor air movement could have important implications for these processes. Therefore, in a controlled-climate chamber occupied with human volunteers, we measured ultrafine particles initiated from ozone-human chemistry and their dependence on air change rate (ACR, 0.5 h^{-1}, 1.5 h^{-1}, and 3 h^{-1}) and operation of mixing fans (on and off). Concurrently, we measured volatile organic compounds (VOCs) and explored the correlation between particles and gas-phase products. At 25-30 ppb ozone levels, humans generated 0.2-7.7×10^{12} of 1-3 nm, 0-7.2×10^{12} of 3-10 nm, and 0-1.3×10^{12} of 10-20 nm particles per person-hour depending on ACR and mixing fan operation. Size-dependent particle growth and formation rates increased with higher ACR. The operation of mixing fans suppressed the particle formation and growth owing to enhanced surface deposition of newly-formed particles and their precursors. Correlation analyses revealed complex interactions between particles and VOCs initiated from ozone-human chemistry. The results imply that ventilation and indoor air movement may have a more significant influence on particle dynamics and fate relative to indoor chemistry.

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Enhancing Air Quality: Investigating Filter Lifespan and Byproducts in Air Purification Solutions

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Air purifiers have become widely implemented in a wide range of settings, including households, schools, institutions, and hospitals, as they tackle the pressing issue of indoor air pollution. With their ability to enhance indoor air quality and create healthier environments, air purifiers are particularly vital when ventilation options are limited. These devices incorporate a diverse array of technologies, including HEPA filters, active carbon filters, UV-C light, photocatalytic oxidation, and ionizers, each designed to combat specific pollutants and improve air quality within enclosed spaces. However, the safety of air purifiers has not been investigated thoroughly and many questions and concerns still arise when applying them.

The goal of this study is to investigate the lifespan of filters as well as investigate the potentially harmful effects of air purifiers. Understanding the lifespan of filters used in air purifiers and the potential formation of harmful byproducts is essential for ensuring their optimal performance, guiding consumers in their purchasing decisions, and establishing industry standards for safer and more effective air purification solutions.

Certain air purification technologies, such as UV-C light or ionization, can unintentionally generate undesirable byproducts that can negatively affect indoor air quality and health. It is well-established that these technologies can inadvertently generate nanoparticles or convert common gaseous compounds into harmful ones, thus exacerbating air pollution. However, the formation of byproducts can vary across products, necessitating further investigation. There is a particular concern about the formation of the carcinogenic substance formaldehyde from common gases like acetone.

Many air purifiers use mechanical filtration to remove particles, dust, and pollen from the air. Filters need to be replaced periodically for optimal efficiency, resulting in an additional cost for end-users. Currently, there are no guidelines for filter lifespan, and therefore, replacement recommendations solely rely on manufacturers. Our market screening revealed that manufacturers' recommended lifespans vary greatly (from 1 month to 10 years), hence, there is a need for general recommendations to guide consumers.

Activated carbon filters are used to adsorb various types of chemicals that can pose health risks or cause unwanted odors. These filters have a certain capacity before becoming saturated. If not replaced in a timely manner, the adsorbed substances are likely to be released from the filter through off-gassing or losing adsorption efficiency. We will present results from around 20 air purifiers representative of the current market. Results will show how the lifespan varies across products and will contribute to establishing recommendations for standardization and regulations.

Development of an Antiviral Electrostatic Precipitator to Prevent Airborne Transmission within Indoor Air Environments by Dry-aerosol Antiviral Coating Method

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The attention on airborne viruses as indoor air pollutants has intensified, given their potential to spread diseases through aerosols. A prime illustration is the global outbreak of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), responsible for the recent COVID-19 pandemic, notably in indoor environments. Consequently, ensuring optimal indoor air quality becomes paramount to control the airborne transmission of virus-laden aerosols, mitigating their occurrence and widespread dissemination indoors (Sachs et al., 2022).

In addressing airborne transmission within indoor air environments, the utilization of electrostatic precipitators (ESPs) emerges as an advantageous and established strategy for enhancing air quality in air conditioning systems. ESPs operate by capturing airborne viruses onto a collection plate. Remarkably, ESPs have been acknowledged for their effectiveness in diverse applications, including indoor air purification, such as indoor air purifiers and air handling unit in building (Chen et al., 2020). As a result, significant efforts have been invested in engineering ESPs with antimicrobial properties, aiming to hinder the transmission of infectious viruses via aerosol fomites.

In this study, we developed an antiviral ESP system with antiviral surface treatment on the collection plates by dry-aerosol coating method. The ESP system's capability to eliminate and deactivate aerosolized viruses, including relevant surrogates (MS2 bacteriophage, H1N1, HCoV-229E, and -OC43) representing human and animal respiratory viruses like SARS-CoV-2, was assessed. Moreover, we applied the antiviral ESP system on air handling unit of office, and evaluated its capability to prevent airborne transmission within indoor air environments.

Our study highlights ESPs' potential in managing indoor air pollution, emphasizing their efficiency in bioaerosol removal. We aim to contribute to preventing future outbreaks, like COVID-19, by laying a strong foundation for effective measures.

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Critical Assessment and Source apportionment of Particulate bound-PAHs in Indoor Air of South Asian precinct

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Although many researchers in recent times have been working on the chemistry and composition of Indoor air quality, yet, source determination and nature of pollutants is still a comprehensive area to be explored. With the above stated objective, the present study emphases on 16 USEPA specified PAHs which are allied with particulate matter. Both PM as well as PAHs are some very common and treacherous chemical contaminant accountable for more than a million death globally. PAHs are organic compound which are either attached to PM of various sizes or can exist in gaseous form. Current work precises the concentration of PAHs associated with fine PM i.e., PM2.5 in indoor environment of south Asian precinct (1), further, using receptor modelling technique for determination indoor sources responsible for the emanation of specific PAHs(2). The toxicity equivalent quotient i.e., TEQ evaluated in the study demonstrations that the highest toxicity among all PAHs is exhibited by BaP followed by InP, BKF, BbF. Seasonal variations in the concentration of PAHs and their respective sources were also established using PMF models, which depicted the domination of 3-ring PAHs in winter with 42% contribution in outdoors, whereas, four-ring PAHs dominion in indoors. Similarly, in summer two-ring accounted for 35% in outdoors, and three-ring PAHs contributed highest with 26.8% in indoors. In monsoon PAHs with two-ring contributed highest with 45.2% in outdoors, whereas, 2-ring PAHs contributed 38.3% in indoors. Also, IDW mapping and molecular diagnostic ratio were assessed for an intense study on distribution of PAHs in the locality and the source apportionment purpose respectively. To the best of our knowledge, the study is first of its kind in this part of the world where, majority of the countries are either developing or under-developed and hence at greater risk to the noxious effects which are often overlooked. The study will provide a clear picture regarding the indoor sources of the PAHs and further help the further professionals to build a credible and pragmatic mitigation technique accordingly.

Keywords- Polycyclic aromatic hydrocarbon, positive matrix factorization, toxicity equivalent quotient, indoor air pollution, molecular diagnostic ratio, IDW mapping

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Impact of Energy Retrofitting on Indoor Particulate Matter Levels in Finnish and Lithuanian Multifamily Dwellings

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Airborne particulate matter (PM) is recognized as a significant indoor pollutant due to its complex composition and detrimental health impacts. The fine fraction of PM, specifically particles smaller than 2.5 micrometres (PM2.5), has been linked to a range of serious health issues, including both fatal and non-fatal cardiovascular diseases [1]. This research study investigates the impact of energy retrofitting on variations of airborne particulate matter (PM) concentrations in multifamily apartment buildings in Lithuania and Finland. In this study, 66 multi-family buildings in Finland (Tampere, Hämeenlinna, Imatra, Helsinki, Porvoo, and Kuopio) and Kaunas in Lithuania, both retrofitted and control, were assessed for PM concentrations. Measurements of PM concentrations were performed during the heating seasons of the years 2012-2015 and 2022-2023 and involved the measurement of indoor PM concentrations in the living rooms and bedrooms of the apartments. Measurements were taken before and after the retrofit activities, and the data was analysed to evaluate the impact of the retrofits on the indoor PM concentrations [2]. The results showed that the retrofit activities had an impact on the PM concentrations in both countries and revealed variations in PM concentrations post-retrofit, providing critical insights into the effectiveness of energy retrofitting measures in improving indoor air quality in different building environments. Additionally, the study found that the impact of the retrofit activities varied depending on the ventilation system in the buildings. In buildings with mechanical ventilation systems, the retrofits had a greater impact on PM concentrations compared to buildings with natural ventilation systems. The retrofit activities evaluated in this study can be considered effective measures for reducing indoor PM concentrations and improving indoor air quality.

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Impact of Building Renovation on Indoor Particulate Matter Levels in Finnish and Lithuanian Dwellings

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Airborne particulate matter (PM) is recognised as a significant indoor pollutant due to its complex composition and detrimental health impacts. The fine fraction of PM, specifically particles smaller than 2.5 micrometres (PM2.5), has been linked to severe health issues, including fatal and non-fatal cardiovascular diseases [1]. This research study investigates the impact of energy retrofitting on variations of airborne particulate matter (PM) concentrations in multifamily apartment buildings in Lithuania and Finland. In this study, 66 multi-family buildings in Finland (Tampere, Hämeenlinna, Imatra, Helsinki, Porvoo, and Kuopio) and Kaunas in Lithuania, both retrofitted and control, were assessed for PM concentrations. PM concentrations were measured during the heating seasons of 2012-2015 and 2022-2023 and involved the measurement of indoor PM concentrations in the living rooms and bedrooms of the apartments. Measurements were taken before and after the retrofit activities, and the data was analysed to evaluate the impact of the retrofits on indoor PM concentrations [2]. The results showed that the retrofit activities impacted the PM concentrations in both countries and revealed variations in PM concentrations post-retrofit, providing critical insights into the effectiveness of energy retrofitting measures in improving indoor air quality in different building environments. Additionally, the study found that the impact of the retrofit activities varied depending on the ventilation system in the buildings. In buildings with mechanical ventilation systems, the retrofits significantly impacted PM concentrations more than in buildings with natural ventilation systems. The retrofit activities evaluated in this study can be considered effective measures for reducing indoor PM concentrations and improving indoor air quality.

[1] Chi et al. *Environ Health Perspect*, **2016**, 124(12):1840-1847.
[2] Prasauskas et al. *Building and Environment,* **2014**, Vol. 76:10-17.

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Conference Topic: *Nanoparticle formation and transformation*

Sources of ultrafine particles at a typical rural site in Switzerland

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Atmospheric aerosol particles are known for their adverse effects on human health and Earth's climate. Among those, a class, namely ultrafine particles (UFPs), is critical given the particles' high number concentrations in the atmosphere and their capability to travel deep into the human body and to deposit onto sensitive body parts e.g. brain and heart [1]. Therefore, scientists dedicated a large fraction of research to advance the understanding of the chemical composition, source and sinks of UFPs.

UFPs are found to be more abundant close to source area, e.g. traffic and industry compared to more remote locations subject to limited anthropogenic activity. However, UFPs can also form in the atmosphere from gaseous precursors via a secondary process known as new particle formation (NPF).

Studies conducted in Switzerland have highlighted the presence of UFPs in urban areas, with transportation-related emissions being a significant primary source [2]. Additionally, Switzerland's proximity to various industrial regions in Europe underscores the role of transboundary pollution in contributing to UFP levels [3].

In this study, we will delve deeper into the outdoor sources of UFPs observed in Payerne, an ACTRIS (The Aerosol, Clouds and Trace Gases Research Infrastructure) and NABEL (National Air Pollution Monitoring Network) site at a typical rural location in Switzerland. We aim to quantify the primary and secondary fractions of UFPs.

Our results show comparable UFP levels throughout the year. Besides traffic (visible in Fig. 1 during rush hours) and residential heating, we explore the roles of airport emissions and long-range transport of black carbon aerosols from forest fires in increasing UFP concentrations. Besides primary emissions, we observe local NPF events evident from the increase in cluster ions and nucleation mode particles concentrations, especially in spring and summer (Fig. 1, Fig. 2). In this work, we further explore the contributions of ammonia and amines from agriculture in enhancing NPF rates in Payerne.

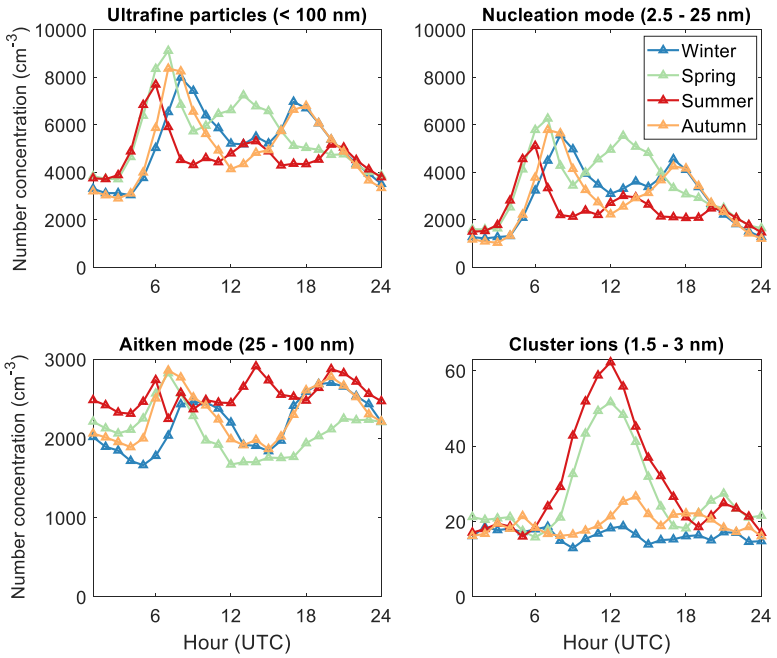

Figure 1. Hourly average seasonal variations of ultrafine, nucleation mode and Aitken mode particles and cluster ions (positive) in Payerne.

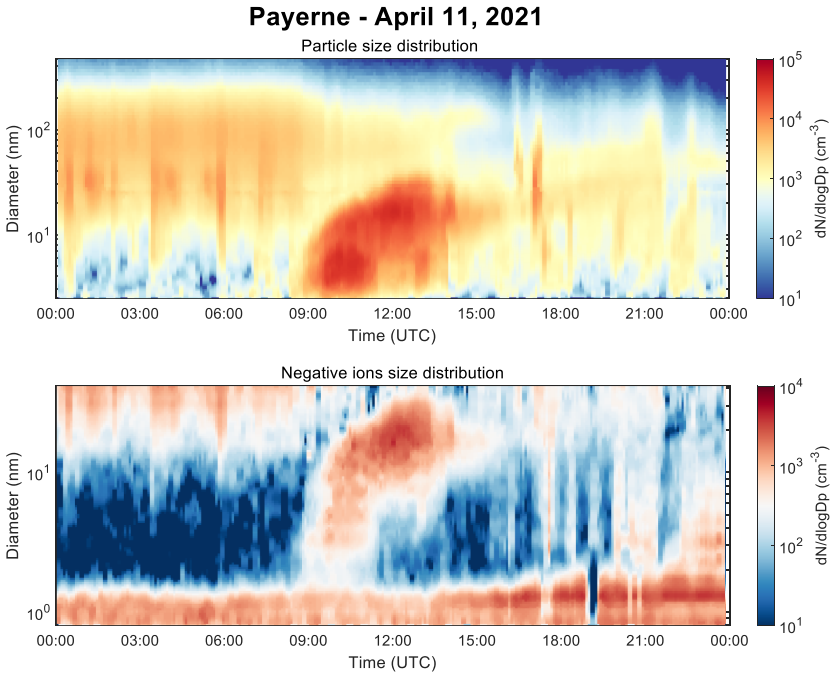

Figure 2. Particle (upper) and ion (bottom) number size distributions on April 11, 2021 in Payerne.

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Rapid formation of aerosol precursors from o/m/p-Xylene and their contribution to secondary organic aerosol formation

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Aromatic compounds contribute significantly to the formation of tropospheric secondary organic aerosol (SOA) that have strong implications on health and on climate. While combustion generated small hydrocarbons are in decline, several single-ring aromatics persist or even exhibit upwards trends in certain urban environments due to their extensive usage in solvents, paints, adhesives, self-care products, and so on [1, 2]. Thus, the sources of aromatics are primarily anthropogenic, yet occasionally biogenic sources can be significant too.

Xylenes (C_8H_{10}) are a group of three dimethylbenzenes that differ by the position of their methyl substituents, and thus provide an ideal testbed for molecular oxidation mechanism generation. To form SOA, the volatile xylenes need to oxidize to low volatility aerosol precursors with multiple oxygen containing polar functional groups, ultimately up to highly oxygenated organic molecules (HOMs) [3,4]. They do this through the autoxidation mechanism, which is a sequential process involving repeated peroxy radical isomerization processes and oxygen additions, and often rapidly terminates to products with carbon to oxygen ratio above one. Recently, we showed that the crucial aromatic oxidation intermediate, the bicyclic peroxy radical (BPR), associated with toluene oxidation is unstable and its decomposition is pivotal to the following autoxidation and subsequent HOM formation. Here we establish the general importance of this aromatic derived BPR decomposition to the formation of SOA.

We have performed a joint theoretical-experimental characterization of *ortho*-, *meta*- and *para*-xylene oxidation pathways towards multifunctional aerosol precursors. The experimental work was conducted in a glass flow reactor (5 cm o.d. and 100 cm length) under ambient conditions with variable reaction time controlled by a moveable injector or by changing the flow rate through the reactor. Nitrate chemical ionization mass spectrometry was used for reaction product detection. Detailed quantum chemical computations on the reaction mechanism supported by master equation modelling of the corresponding reaction rates were conducted to validate the importance of the newly found BPR rearrangement pathway and to verify the timescales required for the highly oxygenated reaction product detection. Finally, the isomeric xylenes were oxidised in an environmental chamber and the resulting SOA yields were quantified by Aerosol Mass Spectrometry.

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Evaluation of Monodisperse Silver Particle Sintering Using a Tandem DMA Setup

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Apart from silver ultrafine particles being used in a broad variety of applications for years (Ankilov et al., 2002, Giechaskiel, et al., 2009, Wiedensohler, et al., 2017), sintering of silver particles has been of special interest to researchers (Ku, B. K., et al., 2006; Zihlmann, S., 2014; Tuch, T., 2016; Silva, E. Z., 2019). The work shown here is aimed at bringing more repeatability and usability to various fields of aerosol science which use sintered silver nanoparticles.

It has been shown that a very stable and reproducible silver particle generation is possible, achieving +- 1 % in GMD, and +- 1,25 % in total concentration while offering a usable size range of 2 – 200 nm (Berger, V. et al., 2023). This opened the possibility to extend these capabilities to other applications, e. g. calibration of automotive CPCs, PNCS, and PEMS. These applications pose more demanding requirements to the aerosol generation: As these systems use sections heated to 350 °C to remove volatile particles (as part of the so-called Volatile Particle Remover, VPR), it is essential that any particles used for calibration are thermally stable (Giechaskiel, B., 2018). It has been shown that sintering of metallic nanoparticles starts at temperatures well below the melting temperature of the respective material (Ku, B. K., et al., 2006). For silver, first sintering effects can be observed at temperatures around 100 °C. To confirm these effects and determine their magnitude for typical VPR systems, the authors present results for silver particles sintered in a heated tube (mimicking an Evaporation Tube, ET) and silver particles sintered in a catalytic stripper (CS). To minimize unwanted effects (especially agglomeration after sintering) and match conditions typically found during PEMS or VPR calibration, a tandem DMA setup is used. Additionally, this approach facilitates the analysis of results. A schematic of the experimental setup is depicted in Figure 1.

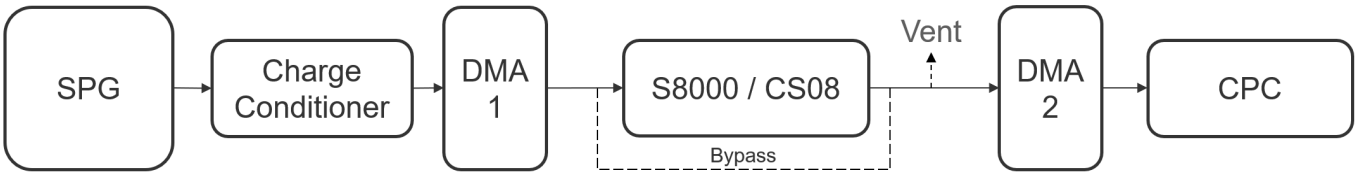

Figure 1 Experimental setup. Silver particles are generated in the Silver Particle Generator (SPG), charge conditioned and size-selected in DMA 1. Subsequent sintering takes place in a S8000 Sintering Stage, a CS08 Catalytic Stripper or is bypassed. DMA 2 and the CPC perform particle size distribution scans.

Sintering reduces the electrical mobility diameter of a particle (Ku, B. K., et al., 2006). This reduces the effective usable size range of the forementioned silver particle generator. To tackle this, the authors investigate methods to increase the particle size before sintering. As it has been shown that higher furnace temperatures lead to larger particles (Berger, V. et al., 2023), we show silver particle size distributions generated at 1150, 1200 and 1250 °C. Because agglomeration of particles yields larger particles, we show the effect of introducing a residence chamber in between the furnace and the sintering stage.

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Real-time measurement of total and solid particle fraction in underground mining environment with DC based sensors (MPEC+)

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In an underground mining environment, the primary particles from vehicles and off-road working machinery are an important pollution source affecting the air quality in an underground mine [1]. These volatile and non-volatile particles affect occupational health as well as economy of the mine because the ventilation demands substantial amount of energy. In addition, air quality is affected by mining activities such as blasting, crushing ore, and transporting ore from the mine. Moreover, non-volatile soot or metallic particles nanoparticles may originate from the diesel engines due to incomplete combustion or from the lubrication oil ash components entering the cylinders. Volatile nanoparticles can be formed during the expansion and dilution of the engine exhaust from the tailpipe to its surroundings due to e.g. sulfur, nitrogen, and hydrocarbon containing gaseous species. These engine originating nanoparticles exist mainly in the ultra-fine particle size range (UFP, diameter < 100 nm), and therefore, the number concentration is a metric that measures the concentration of UFP's. In addition, the volatility of UFP's is an indicator for particle origin and composition.

A system to determine real-time total particle and solid particle number concentrations (TPN and SPN) and fraction of SPN was developed from two diffusion charger based MPEC+ instruments (Dekati Ltd.) In this study, two MPEC+ devices were used as stationary measuring devices for TPN and SPN concentration in an underground mine, located nearby the city of Kemi at northern Finland. The structure of MPEC+ consists of an optional heated sampling line, water separator, evaporation chamber for volatile particle removal (VPR) with an integrated heated critical flow orifice, diffusion charging and diffusion collection based ePNC sensor [2] and a Faraday cage electrometer. The device also includes a three-way valve for automatic zero level measurements for long-term measurements. Typical DC-based instruments have particle size dependent response with linear relationship to Lung Deposited Surface Area (LDSA). In fact, DC-based sensors have previously been used in a mine for LDSA monitoring [3]. However, the particle size response of MPEC+ is close to a pure number concentration response due to the ePNC sensor being operated in reduced pressure conditions which affects both the diffusion charging and particle collection by diffusion [2]. In addition, MPEC+ has been shown to comply with the PN-PEMS requirements when the evaporation chamber is used for VPR in the size range of 23 – 200 nm [4]. In this study one MPEC+ was used in typical configuration with the evaporation chamber removing volatile particles and thus measuring SPN. The second MPEC+ was modified to operate without heating the evaporation chamber, in which case the measurement corresponds to TPN including both volatile and non-volatile particles.

Figure 1 shows the real-time number concentration of total and solid particles and the solid particle fraction at the maintenance level of the underground mine over one measurement day. The solid fraction varied on this day around 5% - 20%. Daily averages of solid and total particle number concentrations were found to be higher at the maintenance level compared to the location near a blasting site. At the maintenance level, the maximum daily concentration of TPN was ca. $4x10^5 cm^{-3}$ and the SPN ca. $1.5 x10^4$ cm^{-3}. The volatile particle fraction behaved oppositely, as the daily average fraction of solid particles was

in maximum 31 % near the blasting site and 12 % at the maintenance level. This results suggest that volatile particles were mainly produced by the traffic inside the underground mine.

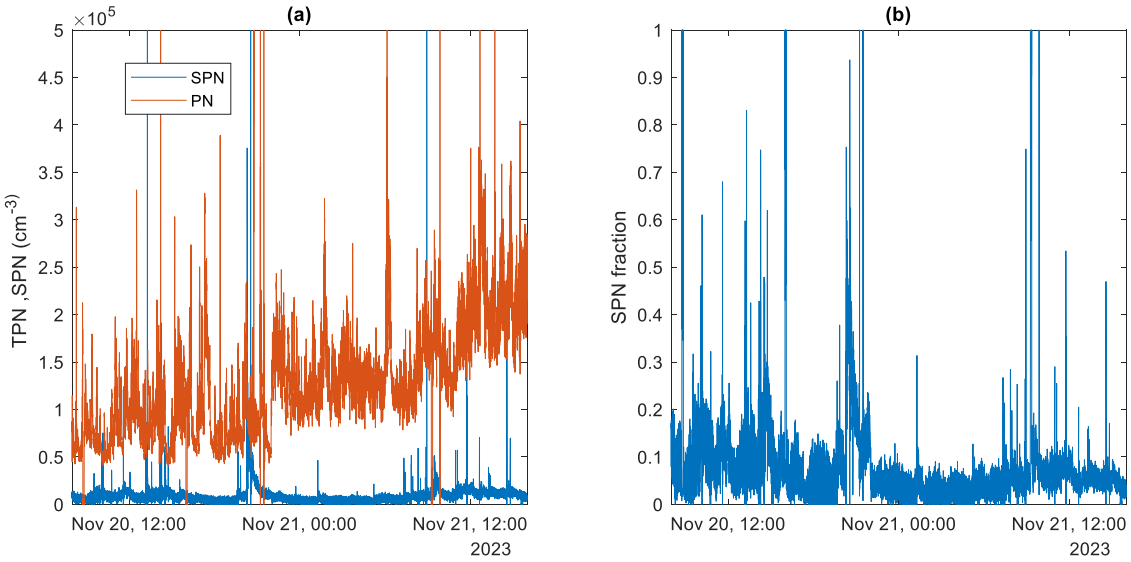

Figure 1. (a) Solid particle number concentration and total particle number concentration (b) solid particle fraction of total particle number concentration.

ACKNOWLEDGEMENTS

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Airborne PM generated from handling of crushed carbon nanotube-enhanced concrete

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Nano-enabled building materials may improve the performance and functionality of buildings, e.g. by improving their durability or, in the case of carbon nanotubes (CNTs) as additive, improving mechanical strength as well as enable self-sensing to detect crack formation. Concerns are being raised regarding health risks from occupational exposure to dust generated from these materials, and it is currently not known if, or how, CNT added to the concrete will affect the aerosol created when CNT-enhanced concrete is crushed during demolition or secondary use.

To investigate this, three types of CNT-reinforced concretes were prepared using NC7000™ Multi-Walled Carbon Nanotubes (MWCNTs) (⌀: 9.5 nm, l: 1.5 µm) at mass concentrations in 0.05 to 0.5%. The types of concrete were Low density, Normal, and High strength, which were crushed to simulate demolition. Concrete fragments <850 µm were systematically resuspended in a continuous drop set-up based on the EN 15051-3 standard further developed for the specific purpose. The formed aerosol was sampled with online instruments (Aerodynamic Particle Sizer (APS), Condensation Particle Counter (CPC), DustTrak (DT), Nano Tracer (NT), Scanning Mobility Particle Sizer (SMPS)) as well as filters for gravimetric-, Scanning Electron Microscopy (SEM)- and Organic Carbon Elemental Carbon (OCEC) analysis.

Addition of CNTs significantly decreased mean particle number concentrations (PNCs) across the entire characterized size range (7 nm - 20 µm) for low density concrete, whereas the opposite was the case for normal strength and high strength concrete. It was hypothesised that the concrete matrix primarily governs the PM formation, which is in turn modulated by CNT-matrix interactions either suppressing or supporting fragmentation during crushing.

SEM imaging (Figure 1) showed irregularly shaped concrete fragments with partially exposed CNTs protruding from the concrete matrix but no free fibres could be identified

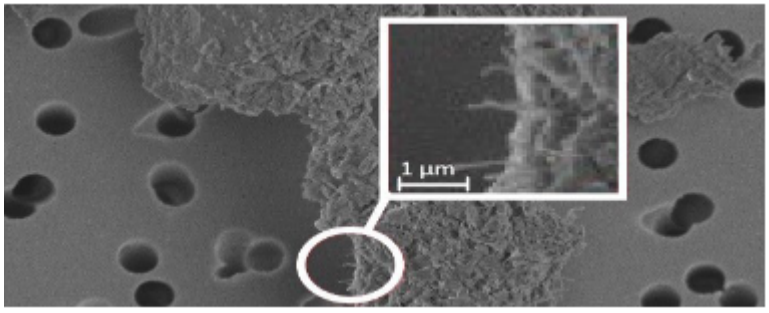

Figure 1: Type 3 with 0.5 wt% CNTs

The majority of the detected particles, regardless of concrete type and wt% CNTs, were within the respirable fraction, i.e., < 4 µm. We therefore stress the development of standardized, matrix-sensitive testing protocols for assessing the risks of occupational exposure related to applications of engineered nanomaterials in the construction sector.

This work was founded by AFA Insurance (dnr 200107).

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Conference Topic: *Occupational exposure and prevention*

Workplace exposure to airborne particles in the plastics recycling and manufacturing industry

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Airborne microplastics represent an emerging health concern and there is significant interest in mapping their prevalence in indoor and outdoor environments. Surprisingly little attention has been given to plastics exposures in factories themselves. The object of this study is to survey the levels and characteristics of particulate matter (PM) in a plastics manufacturing company where part of the raw materials are recycled plastics. In this presentation, we report on our findings from two measurement campaigns. We measured particle number concentrations and size distributions associated with emissions from extruding machines, rolling machines, mixing stations, crushing machines, and thermoforming machines. We used gravimetric methods to quantify total and respirable dust; scanning electron microscopy to characterize particle morphology and chemical composition; and a small rotating drum to measure the dustiness for a collection of the frequently used raw materials, mainly different variations of polyethylene terephthalate (PET). We found that the dustiness for the materials studied were all low, less than about 6 mg/kg, and dominated by micron-size particles. In the factory, the average total particle number concentrations measured ranged from about 4,000 to 100,000 cm^{-3}, with the highest numbers near the rolling and extruding machines. The fraction of courser µm-size particles was low, but important when handling recycled materials and at feeders. Respirable dust concentrations were generally very low (7 to 13 $\mu g/m^3$) and total dust concentrations were similar. This was consistent with our observation that most particles were in the fine (<300 nm) and ultrafine size range (<100 nm). Microscopy indicated that a fraction of the collected particles was composed of synthetic polymer. We conclude that exposure to airborne fine and ultrafine plastic particles may be a matter of concern for those working in close proximity to some of the common plastics processing machines.

Personal exposure to particulate matter during grinding of dental nanocomposite

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During abrasive operations in dental offices, particles of different sizes are released into the air. Currently used dental composites may contain 50 – 70 % of nanosized filler particles. There is a serious concern that medical staff could inhale nanoparticles during composite procedures and that this could have a negative effect on their health. 24 participants were exposed to aerosol particles during four dental nanocomposite grinding experiments (6 participants per experiment). Novel active personal nanoparticle samplers (PENS, PM4-0.1 and PM0.1) were used to determine personal exposure, and the results were compared with the data from a Berner Low Pressure Impactor (BLPI, 10 size fractions in the range 0.026 – 13.7 µm) and a tandem of online instruments including a Scanning Mobility Particle Sizer (SMPS) and an Aerodynamic Particle Sizer (APS) measuring in the size range 0.01 – 20 µm.

Time behaviour of number concentrations of the respirable fraction (PN4) and nanoparticles (PN0.1) measured by the SMPS/APS tandem is shown in Fig. 1. The results revealed that grinding nanocomposite material is a significant source of respirable particles including nanoparticles in the indoor air. Both fractions showed increase at the beginning of the nanocomposite grinding round, with maxima achieved at the end of grinding round, and followed by subsequent decrease to background values.

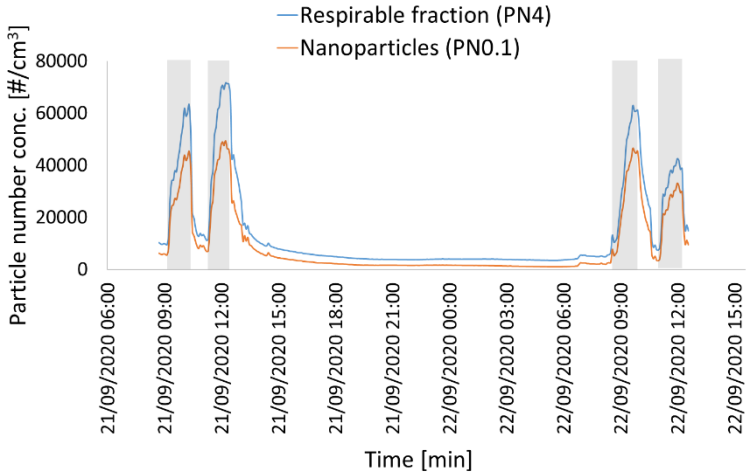

Fig. 1: Time behaviour of number concentrations of the respirable fraction (PN4) and nanoparticles (PN0.1) concentrations (grey coloured areas represent individual grinding rounds)

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Occupational exposure risks of hazardous biological agents in an animal testing facility

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Animal testing facilities play a crucial role in biomedical research, but the presence of hazardous biological agents (HBAs) poses potential health hazards to the personnel involved. The HBAs can be found in bioaerosols, for example, organic dust, bacteria, viruses, animal faeces, animal hair or urine. Exposure to HBAs may, depending on the classification of the organism, result in, inflammatory responses, respiratory diseases, digestive tract infections and general discomfort. Exposure to HBAs is for the most part, accidental or non-intentional and the main exposure routes are inadvertent ingestion and inhalation (Davidson al., 2020). This study aimed to determine the presence of potential HBAs within an animal testing facility using active and passive sampling techniques in various types of rooms hosting different activities. Bioaerosol samples were collected using an active air sampler and a non-selective agar medium plate. Surface swabbing samples were collected (swabbed) according to the prescribed NIOSH method [2] (NIOSH, 2017), After which the samples were incubated on tryptone glucose extract agar (TGE), a non-specific medium for the growth of common biological agents, as well as a select group of other agar plates to target specific types of organisms e.g., m-Green agar for yeasts and moulds and Chromogenic coliform agar (CCA) for growth of *Escherichia coli* and coliforms growth. The HBAs were categorised based on morphological differences and quantified by counting the growth of colony-forming units on the plates. The areas that contained the highest number of colony-forming units (CFU/cm^2) were both washing areas and the entrance of the facility where personal protective equipment is stored. HBAs were also quantified in the hallways that lead to clean and dirty areas within the facility. The lowest number of microbial growth (CFU/cm^2) was observed in the experimental rooms where the animals are handled, and tests are conducted. Since the identity of the HBAs was not confirmed during this study, pathogens might be among the detected HBAs. This study proved the presence of potential HBAs and warrants the need for regular monitoring and more in-depth analysis of the types of potential HBAs. Based on the findings, it is recommended that the animal testing facility enhances safety measures to minimize occupational risks. This may include improvements in facility design, updates to safety protocols, and recommendations for ongoing training and education for personnel. The goal is to develop a comprehensive risk management plan that ensures the well-being of the workers in the animal testing facility while maintaining the integrity of scientific research involving hazardous biological agents.

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Aerosols, a tool for assessing airborne transmissions of hazardous substances and agents

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How do you assess the risk of aerosols carrying hazardous substances and biological agents? How can companies protect products and their workers? Understanding airflow and ventilation is central to understanding airborne transmission and therefore to successful risk management. Aerosols can be a useful tool for this assessment.

The movement of aerosols sized a few micrometers is determined by the air around them. These aerosols are too large to diffuse and too small to sediment rapidly. In well-mixed rooms, their concentration is highest near the source and decreases with distance. But many rooms are not perfectly mixed. Instead, the airflow is often directional, frequently chaotic. This flow together with eddies defines where the emitted aerosols go, how long they stay airborne and how well they mix in the air.

A practical approach to assessing airflow and ventilation in real environments is to use pulses of theatrical fog or salt crystals released at locations with an assumed source. Theatrical fog allows direct visualization of the movement of the aerosol cloud. A network of sensors can help determine the time from release to impact at other locations in the room. Dose quantification is also possible using peak area, emission duration and rate of the passing cloud together with fog evaporation parameters. However, the stability of theatrical fog is not always sufficiently predictable. In such situations, more stable aerosols such as salt crystals can be used instead. This approach can be used to assess airflow, ventilation and aerosol transmission in real-world situations such as operating theatres, factories, schools, offices and concert halls. The visual effects of theatrical fog are also very useful in persuading workers and decision-makers alike to take the necessary protective measures.

Towards implementing particle chemical composition in health impact assessments

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Atmospheric particulate matter is responsible for seven million premature deaths annually and incurs 5% of the global GDP. In 2021, the World Health Organization (WHO) updated their regulations, imposing a stringent limit of 5 µg m-3 for PM concentration. However, this limit is rarely met, and more than 97% of the global population lives above these limits. Current WHO regulations oversimplify PM as a uniform entity based solely on total mass concentrations, despite its complex composition and variable toxicity. Identifying the most harmful PM component has remained the Holy Grail of air quality research. With the availability of detailed atmospheric data, there is an opportunity to shift our focus towards understanding the specific health effects of individual PM components. Our research aims to determine concentration maps for individual PM components at resolutions as fine as 100m for the entire European domain, which is crucial for establishing the health impacts of PM components.