Diffusion-charging based sensors for ambient air quality measurements

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[1]Naneos particle solutions

Ultrafine particles are suspected to be particularly health-relevant due to their small size, which allows them to penetrate deeply into the lung, and to cross cellular barriers that larger particles cannot cross. So far however, regulations usually only consider particle mass, with PM10 and PM2.5 being widely measured, and corresponding limit values are in place. Ultrafine particles (UFP) in ambient air have so far only been measured optionally for research purposes. This is about to change though with new WHO recommendations asking for specific UFP measurements, ideally with size resolution; and in particular with a new EU directive which mandates UFP measurements of particle number concentration (PN) and particle size distributions (PSD). Reliable and well-known instruments to measure these two new metrics exist; the condensation particle counter (CPC) for PN, and the mobility particle size spectrometer (MPSS) for PSD. These instruments will also be used to implement the new EU directive. However, this directive asks for a very low geographic coverage: one measurement site must be implemented for each 5 million inhabitants. If we translate this to a country like Switzerland, it would need only two sites measuring UFPs to fulfil the new directive - which is obvioulsy far too little to gain any understanding of the spatial distribution of UFP. This low coverage is rather absurd, since UFPs are know to be very inhomogenously distributed compared to PM-based metrics. One reason for the currently low mandated spatial coverage is the complexity and cost of the instruments used. To understand UFP and their spatial distribution better, instruments are needed which are cheaper, easier to operate, and which can be operated outside of traditional measurement stations. Diffusion-charging based instruments can fulfil these requirements, as they are far smaller, consume less power, need no working fluid and can work within a large range of operating temperatures. At naneos, we have developed two diffusion-charging based devices for ambient air monitoring:

1) The Partector 2 was originally designed for easy handheld UFP measurements, e.g. in workplaces. It was not intended for longer-term deployments, and certainly not for 24/7 ambient monitoring for long periods (e.g. 1 year) without service. However, some of our customers started using it for such measurements, and we have since started our own testing of the Partector 2 Pro at different measurement sites in Switzerland where the PSD is measured with conventional MPSS systems. The first such measurements were started in mid-2023, and by now, we have 6 Partector 2 devices measuring at 3 different sites: Zürich, Payerne and Jungfraujoch.

2) For the EU project Net4Cities we developed an entirely new low-cost OEM sensor which only measures lung-deposited surface area (LDSA). LDSA is not among the newly mandated metrics for UFP, but there are toxicological and animal studies showing that it might represent health effects better than either particle number or particle mass. From an instrumentation perspective, LDSA instruments are much simpler than diffusion-charging based particle number measurements such as the Partector 2, and therefore they are cheaper, less prone to failure, and also far more robust, leading to much lower total cost of ownership. One can therefore deploy a far larger number of such devices in far more places to study UFP than when using traditional instruments.

We have also designed an ambient enclosure which accepts either the Partector 2 or the low-cost OEM sensor, and comes with internet connectivity, so both systems can be installed anywhere where mains power is available, e.g. on a lamp post, rather than needing a climatized measurement station. We will present comparisons of our devices vs MPSS and CPCs, and some of the issues found in the field with our sensors, and measures taken to improve the Partector 2 for longer term monitoring.

Usage of porous filter and salt solutions for the generation of constant particle concentrations

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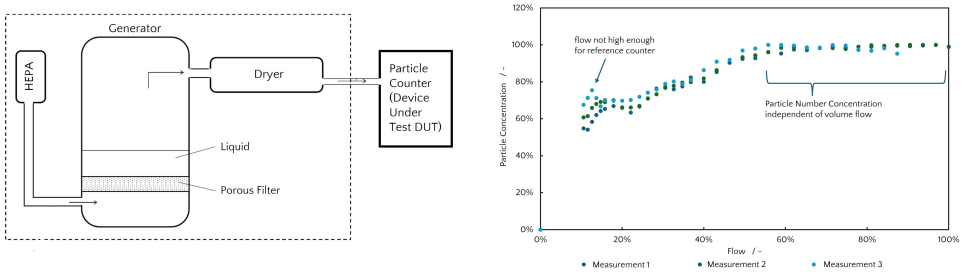
>**Keywords:** #Calibration #Particle Counter #CPC and DC #DailyCheck #Nanoparticle

Porous filters with defined pore sizes are used in a wide range of technical applications. ISO 4793:1980 specifies classes for the pore sizes, therefore there are well established industrial processes to produce high quality structures with defined pore sizes. In our study we are using a porous structure immersed in a liquid while an air stream is flowing through the porous structure. Gas bubbles of a defined size distribution are formed by the pores and burst on the surface of the liquid. Fine droplets are created in the air steam above the liquid reservoir. If that liquid contains additives, like minerals (for example salt) these droplets can be dried to create solid ultrafine particles of a defined size distribution, depending on the pore size used in the porous filter. Now these particles can be detected with a particle counter (DUT).



For our study we are varying the gas volume flow through the porous structure and observe the generated particle number concentration the DUT is reporting. It turns out that there is a wide window of volume flow, where the particle number concentration is independent of the volume flow and that the generated particle concentration is repeatable, as the sizes of the generated bubbles above the porous structure are uniform for these gas velocities passing the porous structure. Figure 2 shows the generated particle number concentration as a function of volume flow through the porous structure.

Applications and outlook

A weak point of particle counters is that it is very complex to check their function. To ensure that the reading of PN counters is correct, a complex laboratory setup with a particle generator and a reference counter is required. Unlike gas analyzers, that can be checked with a span gas bottle, particle counters can only be checked with a HEPA filter on a daily basis, to find leaks. Real calibrations are usually performed on an annual basis and errors are only recognized after the data collection, so that measurement results become unusable when errors are found. With the porous filter generator we found a very easy and simple way to check particle counters before the measurement is performed on-site (patent pending DE 102024139698.9). As the porous filter generator doesn't need its own compressed air supply or pump, it is an easy and cheap tool for checking the DUT counter before the measurement takes place on site. With switching valves this check can be performed fully automated. Choosing the right geometry and pore size, a suitable generator can be designed for every possible PN measurement application.

Synthesis and characterization of thin films for sensing Bioaerosols

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Abstract:

Detection of biological components in ambient air is a difficult challenge as the methods are cumbersome and time taking. Hence, the development of fast and accurate methods of detection and identification systems for biological components in the environment is of paramount importance in the recent scenario of the infection and spread of pathogens. For that we are synthesizing and characterizing the material which will be used as a tool for making prototype for microbial biosensor which will be of low cost, efficient, highly sensitive and versatile. ZnO electrodes in the form of thin films were prepared with different layer coatings and later characterized to see the biosensing properties so that biosensors for monitoring and measurements of bioaerosols in the environment can be fabricated. These thin films have been prepared using sol-gel method and characterization were investigated by various techniques such as FE-SEM, UV-VIS and XRD. The electrical behavior of the electrode has also been studied and plotted into I-V curve, ranging from -1 to 1 V which shows the fluctuation in current on applying voltage. It is predicted that 2- layer thin films carry more current which makes it suitable for biosensing application compared to 5-layer films on applying bias. This is because if the 5-layer coating becomes too thick, it might suffer from higher resistance therefore reducing current flow.

Keywords: *Ambient environment, bioaerosols, biosensors, nanomaterial*

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Real-world implementation of an optoacoustic Black Carbon Sensor for Ship Emissions Measurement

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Black Carbon (BC) is a byproduct of combustion of carbon-containing fuels, that is defined partly by its strong light absorption properties [1]. It contributes significantly to climate change [2], while it also has adverse effects on human health [3]. Currently, new legislation for BC emissions from ships in the Arctic, is being discussed by the International Maritime Organization. Absorption based techniques that can quantify BC are required for on-board monitoring. Optoacoustics, aka Photoacoustics, is one such promising candidate technology.

We have previously developed a low-cost optoacoustic sensor [4]. A portable version of this sensor was installed on-board a RoRo ferry that was transporting passengers and cargo in the Baltic Sea. The ferry was powered by four medium speed 4-stroke main engines, it was equipped with SCR catalysts, and it was operating on MGO fuel. A diluter was used to provide a sample from one of the main engines to the sensor, while an AVL MSS and an AVL Smokemeter were used as references.

The results of the campaign show that the sensor is suitable for BC monitoring of ships. It was able to monitor the BC mass concentration from the exhaust stack with very good agreement to the MSS. The Smokemeter seems to consistently overestimate BC emissions. Insight on required sampling protocols was also gained. Stable BC concentrations were observed during cruising, as expected. During maneuvering (close to the port) we noticed rapid and very large peaks of BC which can only be captured by continuous measurements. The use of a dilution cycle or long averaging (typically employed by filter-based instruments) should be avoided for accurate emissions estimation.

Acknowledgements
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Urban Air Quality Monitoring with the AVL UltraFine Particle Monitor: Measurement Campaigns and Key Findings

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Ultrafine particles (UFPs, <100 nm) are a significant concern in urban air quality due to their potential adverse health effects. The AVL UltraFine Particle Monitor (UFPM) has been developed to meet the requirements of EN 16976, ensuring high precision in ambient UFP monitoring. This study presents measurement results from long-term urban monitoring campaigns conducted in Graz and Vienna, Austria, providing insights into spatial and temporal variations of UFP concentrations. Results indicate a strong correlation between traffic activity and UFP levels, with concentration peaks observed during morning and evening rush hours. Notably, Graz exhibits ~60% higher UFP concentrations compared to Vienna, attributed to differences in topography, urban structure, and prevailing wind conditions. High-resolution measurements during New Year's Eve further highlight the need for real-time monitoring to capture rapid fluctuations caused by transient events such as fireworks. These findings emphasize the importance of continuous UFP monitoring for urban planning and public health assessments. The AVL UFPM, independently calibrated and ACTRIS-compatible, demonstrates its capability as a robust tool for regulatory and research applications in air quality management.

Seeded Growth of Silver Nanoparticles by Heterogeneous Condensation in a Tandem Silver Particle Generator Setup

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The calibration of CPCs and DMAs needs monodisperse, singly charged, spherical particles (Wiedensohler et al., 2018; EN 16976:2024). A common way to generate these using silver is the evaporation condensation method described by Scheibel and Porstendörfer (Scheibel et al., 1983). Silver is evaporated at temperatures around 1100 °C. The silver vapor nucleates to particles when cooling down. When generating sufficiently high concentrations of particles, agglomeration of these particles generates larger, fractal-like particles. To obtain spherical particles, these agglomerates need to be sintered, i. e. reheated to temperatures in the range of 400 to 700 °C (Ku et al., 2006; Zihlmann et al., 2014; Tuch et al., 2016; Berger et al., 2024). Sintering reduces electrical mobility diameter by approx. 70 % (Zihlmann et al., 2014), as the low-density agglomerates are compacted into solid spheres. The significant reduction in size makes it challenging to achieve spherical silver particles larger than 100 nm (Berger et al., 2024), as agglomerates with an electrical mobility diameter larger than 300 nm are needed. An alternative approach for the generation of spherical silver nanoparticles has been presented (Zihlmann et al., 2014): Seed particles, generated in a spark discharge generator, are sent through a tube furnace operated at 1210 °C. A crucible filled with silver inside the tube furnace generates silver vapor. In the cooler parts of the tube furnace, the silver vapor heterogeneously condensates onto the seed particles, increasing their size. It has been shown that these particles are spherical, and that particle diameters of up to 104 nm are achievable. In a first step, the work presented here aims at reproducing the results by Zihlmann et al. while using two Silver Particle Generators (SPG) by Catalytic Instruments GmbH & Co. KG, Germany. Figure 1 shows a schematic of the experimental setup.

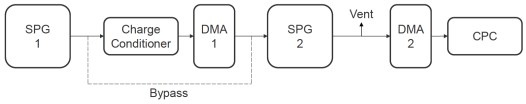

Figure 1: Experimental setup. Silver particles are generated in the first Silver Particle Generator (SPG 1). Optionally, the particles are charge conditioned and size-selected in DMA 1. Subsequently, the aerosol is fed into SPG 2, where silver vapor condenses heterogeneously onto the incoming particles, increasing their size. DMA 2 and the CPC perform particle size distribution scans. The second step is to further investigate the possibilities of this Tandem-SPG (T-SPG) setup. As the SPG is quick in adjusting its operating parameters (temperature, carrier gas flow rate, dilution flow rate), a large field of temperature and gas flow combinations of the two SPGs can be investigated efficiently. Main goals of this investigation are the upper particle size limit of this setup, and whether a monodisperse aerosol can be achieved from polydisperse seeds via supersaturation of silver vapor.

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Session 7: Poster Session B (Instrumentation), Poster

A Fast Wide Size Range Condensation Particle Counter

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This study presents a Condensation Particle Counter (CPC) with a wide size detection range and fast time response. A fast time response is useful to reduce scan times in scanning applications and supports real-time monitoring and the study of dynamic processes. CPCs grow particles by condensation until they are large enough to be detected by optical scatter, allowing it to count particles smaller than the minimum detectable size of Optical Particle Counters. However, many CPC models have low detection efficiency of larger particles (>1 µm) due to particle inertial losses in bends and constrictions in the flow pathway.

The presented CPC uses a laminar mixing design, where pre-vapourised working fluid in a stream of filtered air mixes with the sample. This avoids losses of larger and smaller sampled particles in a saturator. The CPC is of a wholly horizontal design to avoid bends; at the design conditions gravitational settling is not significant <10 µm.

The CPC was tested for large particle (>1 µm) counting with condensation aerosols from a Sinclair Le Mer Generator (modified TOPAS SLG-250) using DEHS as a condensate. Below 6 µm particles were size selected with a Cambustion AAC, and a PALAS Welas 1000H aerosol spectrometer was used as number reference, and above 6 µm for size. A TSI 3752 CPC was also used as a comparator and to correct the WELAS counts by examining their overlap. For intermediate sizes, a TSI 3752 was used as a reference, sampling ambient air or an oil aerosol. For small particles (<20 nm) ultrafine sodium chloride aerosols, condensed from a tube furnace, were size selected with a TSI 3085 NanoDMA, while a PALAS Charme electrometer served as a counting reference.

Particle counting results are collated in Fig 1a – the $D_{50,min}$ was measured to be 5 nm, and $D_{50,max}$ was greater than 10 µm. The time response ($T_{90\text{-}10\%}$) was measured to be <40 ms (Fig 1b).

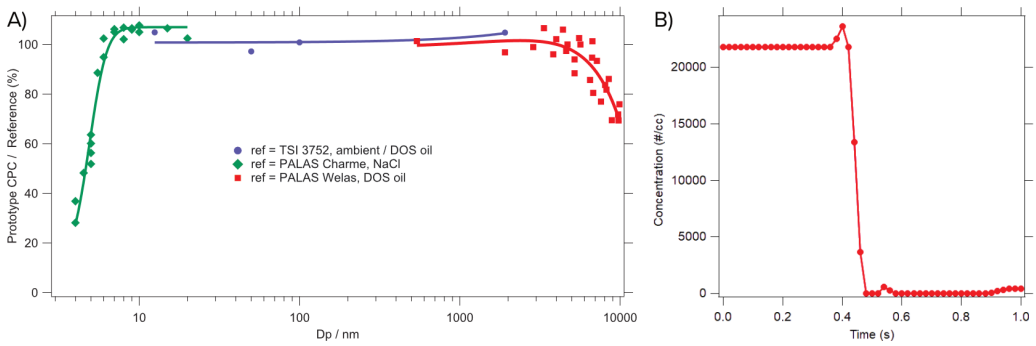

Figure 1: a) Particle counting results over full size range of CPC; b) time response measurement (atmospheric aerosol with HEPA filter added/removed) where each datum is 20 ms.

Session 7: Poster Session B (Instrumentation), Poster

Insights from over two years of using DMSO as working fluid in condensation particle counters

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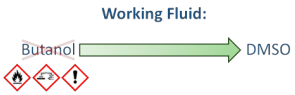
Condensation particle counters are an indispensable measuring instrument in aerosol research. Nanoparticles suspended in the air, also known as aerosols, pose a potential risk to human health and industrial processes. Precise monitoring is therefore essential in many environments, but also in high-security laboratories or clean rooms in the manufacturing industry. The working principle of condensation particle counters is the vaporisation of a working fluid with subsequent condensation onto the airborne particles. The subsequent growth of the particles means that all particles activated in this way can be counted and a number concentration can be determined.

In order to be used as a working fluid, various characteristics are important, including vapour pressure behaviour at different temperatures. To-date, butanol is the most commonly used working fluid in CPCs event though it is associated with a pungent odour, health risks and flammability. Liquid DMSO (Dimethylsulfoxid) does not have the negative properties mentioned above. DMSO, on the other hand, has a similar vapour pressure curve to butanol, but shifted by an order of magnitude, resulting in significantly reduced consumption for the same particle size activation (Weber, et al., 2023).



DMSO as a working fluid has proven its performance in various experiments and a wide range of working conditions including low pressure environments. After two years of operation, we have gained more experience regarding the tolerance to DMSO of various components used inside CPCs. DMSO was used instead of butanol in three Model 5411 Sky-CPC (Grimm Aerosol Technik, Muldestausee, Germany) and a CPC 3772-CEN (TSI Incorporated, Shoreview, MN, USA) without any modification of the CPC hardware.

We will present our findings and discuss any questions regarding applications and experiences made during multiple test-runs and long-term measurements.

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ROS production of source-specific emissions from combustion, brake, tire and road wear

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Grouping by similarity is an established method for extrapolating toxicity pathways for chemicals in general and has also been suggested for nanomaterials [1]. Therefore, such grouping may also be a useful approach when considering source specific emissions. This work will quantify acellular ROS production and oxidative potential (OP) of individual particle components from combustion, brake, tire, and road wear. Detailed particle characterization allows grouping by similarity and identification of source-specific markers that will help improve the mechanistic description of particulate ROS and OP. This can support new health policies and emissions legislation. Within the project, aerosol experiments are primarily performed under controlled generation in laboratory and real-scale simulations. Combustion particles were collected from a miniCAST soot generator, an experimental heavy-duty diesel engine fueled with renewable and fossil diesel, and from fire emissions of real-scale compartment fires during simulated arson. Tire and road wear particles were collected from a road simulator set up with summer, winter-friction, and studded winter tires on a cement concrete pavement. Brake emissions were collected from a pin-on-disc tribometer using different pin materials, relevant to the EU and USA, on a grey-cast iron disc. Screening methods for the generation of road emissions without tire particles will be investigated.

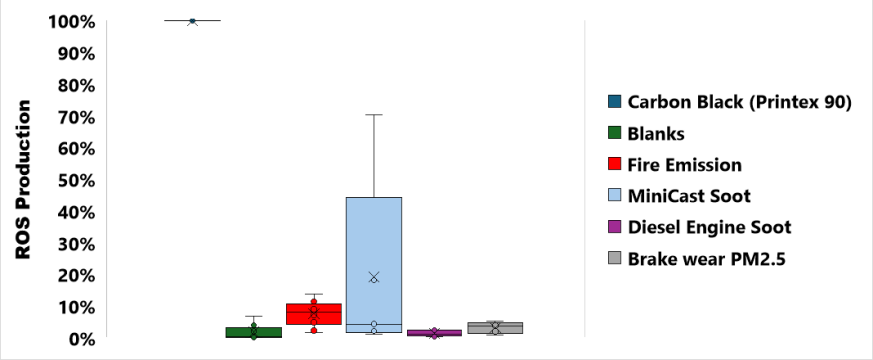

Fig. 1. *ROS production by PM2.5 combustion and non-exhaust particles normalized to Printex 90.*

Particles were collected on Teflon filters and extracted by sonication (3x15 min) in methanol. Fluorescence-based quantification of acellular ROS production was performed with the 2,7- dichlorodihydrofluorescein diacetate ($DCFH_2$-DA) assay. In addition, we plan acellular OP measurements with the dithiothreitol (DTT) assay and a selection of the particle samples will be subject to in vitro and in vivo analysis of relevant toxicological endpoints. We use a well-characterized carbon black nanomaterial (Printex 90, Degussa, DE) with high specific surface area as a positive control, which facilitates further comparison to a broad range of carbon nanomaterials [2]. Preliminary results (Fig. 1) suggest that acellular ROS production per unit mass were of similar magnitude for the tested combustion and traffic-related emissions, but significantly lower than the positive control (1-70%). Future work aims to group particle emissions by similarity with respect to phys-chem characteristics, ROS and OP.

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Real-time simultaneous measurement of carbon and trace metals in brake wear particles using ICP-TOFMS

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This study was conducted under realistic driving and braking conditions of a currently used brake system, using ICP-TOFMS (Inductively coupled plasma time-of-flight mass spectrometry) to measure elements in brake wear particles in real time. Conventional elemental analysis techniques have mainly focused on samples collected by filters, but the ICP-TOFMS equipped with a counterflow denuder in this study succeeded in real-time elemental analysis of brake wear particles as aerosols. In contrast to elemental analysis, which has mainly focused on metal analysis, this study has enabled simultaneous determination of carbon and metal by accurate mass analysis using ICP-TOFMS. Simultaneous real-time determination of carbon and metal in aerosol particles makes it possible to measure not only brake wear particles, but also tire wear particles, exhaust gas particles, and a wide range of other sample types. This study will be presented on the emission mechanism by comparing brake load, brake wear particle composition, and nanoparticle number size measurements.

Characterization of brake wear particles: influence of pad material and braking conditions on particle charging state

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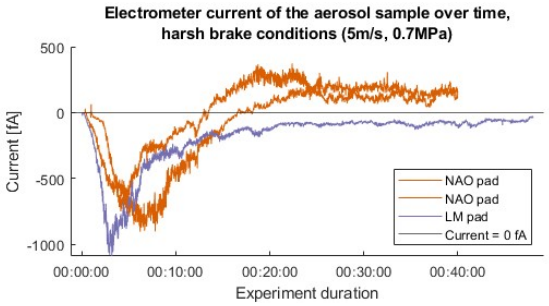
Brake wear particles, generated from the brake pad – disc contact, contribute significantly to particle emissions from vehicle transport, and as the vehicle fleet transitions to electric, heavier, vehicles and alternative fuels, their relative contribution may increase. A recent study suggests that brake wear particles are highly charged, which can affect their atmospheric lifetime and deposition in lungs [1]. Further, determining the charging state of these particles might provide useful information of their initial formation mechanism. This study investigated how brake pad material and braking conditions influence the charging state and electrical properties of brake wear particles. We used a pin-on-disc tribometer to study particles generated from pins from two common brake pad types, low metallic and non-asbestos organic, in contact with a gray cast iron disc. Mild and harsh braking conditions were simulated with a disc speed of 2 and 5 m/s and a contact pressure of 0.6 and 0.7 MPa, respectively. The net charge of the aerosol particles was assessed from electric currents measured with an electrometer. More detailed studies of the charging state were conducted with a scanning mobility particle sizer with and without the bipolar charger (BPC), to compare the electrical mobility distributions of particles with their charge state from the tribological interaction retained to that of particles at bipolar charge equilibrium. We also used a differential mobility analyzer connected to an aerodynamic particle sizer to select particles with a certain, retained, electrical mobility and measure their aerodynamic size distribution. Connecting a BPC to this setup, we could determine the effective density used to convert electric mobility equivalent diameters to aerodynamic equivalent diameters. Additionally, number and mass size distributions were measured across an extensive range of particle sizes. P10 and PM2.5 samples were collected for chemical analysis.



Preliminary results indicate that both brake pad type and braking conditions affect the electrical properties of brake wear particles. For harsh conditions, the electrometer showed a strong negative net charge during the running-in phase, and a pad dependent net charge during steady-state. There was a strong shift in the electrical mobility size distribution measured with and without the bipolar charger, indicating that the particles are highly charged, tentatively around 10-20 charges per particle. The non-asbestos organic pin generated both the highest and lowest mass and number concentrations, during harsh and mild braking conditions respectively. Notably, harsh braking conditions generated a significant increase in nucleation-mode particles.

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Size-resolved Elemental Analysis of Brake Emissions from Popular Brake Linings.

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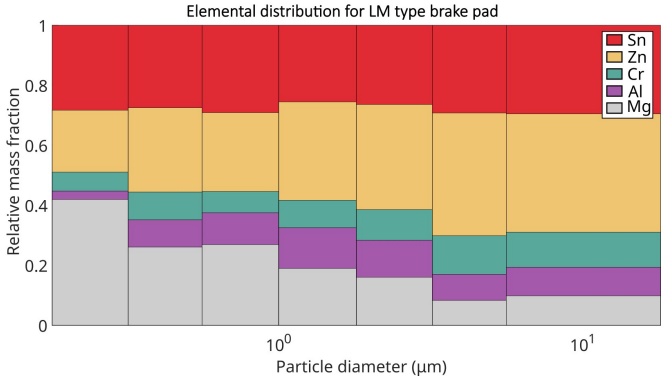
Electrification is expected to have an effect on urban air quality as electric vehicles replace traditional internal combustion powered vehicles. Lack of exhaust emissions from electric vehicles is a key component in this exchange. Additionally, electrical vehicles has been found to be heavier than their traditional counter parts and vehicle weight has been reported to increase emitted non-exhaust emissions (NEE) [1]. A common tracer for exhaust emissions, carbon dioxide, is absent in NEE. Finding such component is essential when quantifying importance of NEE in urban air. In their review article Thorpe and Harrison [2] concluded that multiple authors have proposed Cu:Sb ratio could be used as a tracer for brake emissions. Manufacturers have developed new Copper Free brake pads, which will effect the ability of Cu:Sb ratio to be used as a tracer in the future.

In this study, we used a insulated pin-on-disc tribometer for emissions production. Two different brake lining materials were used, Non-asbestos organic (NAO) and Low-metallic (LM). The pin (10mm diameter) was cut from a brake pad ensuring same material as in commercially available brake linings. Similarly, the disc in the system was made of the same material (cast-iron) as actual brake disc, but in smaller scale. Two different conditions were tested, mild (2 m/s, 0.6 MPa) and harsh (5 m/s 0.7 MPa), where both disc speed and contact pressure varied. We used a 13-stage impactor (MOUDI 125R, TSI) to collect filter samples from which elemental composition was analysed with an X-ray fluorescence spectrometer (EDXRF, Epsilon 4, Malvern Panalytical). Simultaneously, we measured with an Aerodynamic Particle Sizer (APS 3321, TSI) to determine size distribution. We found that the relative mass fractions of elements vary with particle size, indicating that the elemental composition of brake-emitted PM2.5 differs from PM10.



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Physico-chemical characterization of dust generated by a brake for light-duty vehicle applications

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It is well documented in literature that the exposure to particle emissions has a severe impact on public health. Emissions from vehicles, including both exhaust and non-exhaust sources, represent the major contribution to ambient particulate matter (PM). In the last years, the adoption of even more stringent regulatory standards has resulted in an effective reduction of the tailpipe emissions from vehicles. The decreasing trend of exhaust emissions has been accompanied by a gradual increase in the proportion of non-exhaust emissions. A significant source of non-exhaust emissions is represented by the brake wear particles generated from the friction between the brake lining and the rotating components [1-2]. The hazardous environmental impact of brake wear particles has also been recognized by the European Commission that has introduced a limit in the next Euro7 vehicle standards. The adverse effects of PM depend on two factors that are the particle size distribution and their chemical composition.

This study addresses both these aspects by investigating the debris generated by the wear of a brake for light duty application from physical and chemical point of view. A characterization of the particles, in terms of number and size was performed under braking profiles typical of urban driving. To this purpose, a proper experimental setup was designed consisting in a box where the brake was enclosed and connected to an inlet tunnel for the entrance of filtered air and an outlet tunnel for the evacuation of the flow. Two different principle-based instruments were used to characterize the particles in a wide diameter range, the EEPS from 5.6 to 560 nm and the OPS from 0.3 to 10 µm. An in-depth investigation of the chemical composition and morphology of brake wear dust, collected at the end of the braking test on the surface of the chamber was carried out through several techniques, including spectroscopic tools, thermogravimetric analysis (TGA), chromatography, morphological and elemental analysis. This methodology was adopted to analyse a representative sample of the dust deposited on the roadside soil and then resuspended in the atmosphere. On-line physical investigation revealed the presence of particles with size varying between 100 and 6000 nm (Figure 1-a). The particle size distribution is characterized by a bimodal evolution with a first pronounced peak at 200 nm and a second mode centered at 1000 nm. Quantification of the inorganic and organic components in the sample (about 85 and 15%, respectively) has been made possible by an EDX analysis of the collected powder and a thermogravimetric analysis in oxidative conditions. The inorganic portion of the sample is primarily made up of iron and iron oxides, as confirmed by XRD, Raman and ICP. Furthermore, SEM images (Figure 1-b) reveal that the smallest particles are "attached" to the surface of the largest ones, most likely due to oxidative wear. These submicron particles may have a greater effect on human health if inhaled. Raman spectroscopy analysis confirms that the samples is manly composed by an aromatic carbon-based part and iron-based part.

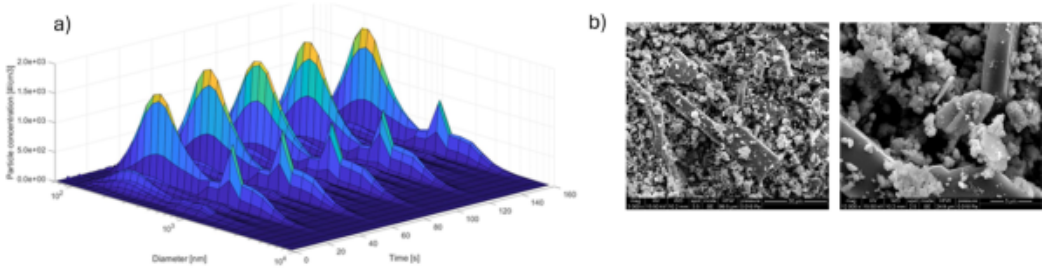

Figure 1.a) Time-resolved particle concentration and size distributions; b) SEM images of debris at two magnifications

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Basic evaluation of brake-emission correlation between chassis dynamometer and brake dynamometer

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Transportation significantly contributes to air pollution, with vehicle emissions playing a major role. The WHO reported 4.2 million deaths in 2019 due to outdoor air pollution, with fine particulate matter being a key factor. A report by the European Environment Agency highlights that non-exhaust emissions (NEE)—from tire, brake, and road wear—now exceed exhaust emissions. The heavier weight of electric vehicles worsens NEE, underscoring the need for effective measurement and mitigation.

The LIFE NEEVE project, funded by the EU's LIFE program under CINEA, aims to develop methods to measure and reduce NEE from brakes, tires, and road interactions. It introduces mobile measurement devices and innovative organoids to assess NEE's effects on human lung and skin cells.

To advance on-board measurement system for NEE we decouple brake emissions from the total NEE on a chassis dynamometer and correlate the measurements with the emissions measured on a brake dynamometer, where the results are also evaluated with respect to the GTR 24 brake emissions testing regulation. Particle number and particulate mass results are supported by particle size distribution scans and evaluation of the toxicology of the filter load through the assessment of cell survival and oxidative stress in skin and lung organoids.

The project establishes a framework for enhancing real-world NEE measurement, supporting regulatory improvements and industrial applications for both combustion and electric vehicles.

Shedding (Synchrotron) Light on Speciation of Metals in Brakes Emissions: a XANES Investigation on Micro- and Nano- Particulates

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Brakes non-exhaust emissions (NEE) are gaining increasing attention in the air quality discussions due to the imminent enforcement of the EURO 7 legislation and the progressive electrification of road mobility. In particular, EURO 7 regulation introduces for the first time in history a limitation on the mass of PM_{10} particles generated by brakes of new passenger cars (PCs) and Light Commercial Vehicles (LCVs) entering the EU market, starting from July 2025. The corresponding legislative process has been sustained in the last decade by significant scientific and technological effort to: *i)* understand mechanisms underlaying the generation of particulates during braking; *ii)* unveil influencing factors leading to different brakes emission levels; *iii)* develop reliable procedures to measure and characterize emissions generated by brake systems; and *iv)* design new automotive brake components able to reduce the particulate emissions. More recently, particular attention has also been paid to the chemical characterization of brakes NEE, since this is pivotal for assessing their toxicological and environmental behavior. At this specific aim, current studies are more frequently focused on unveiling the chemical species composing brakes emissions, which appear more relevant than looking at their elemental composition only. In particular, due to brakes NEE compositional characteristic features, including a dominant content of inorganic compounds, X-Ray Diffraction (XRD) analysis has been proposed and successfully deployed in the last years for evaluating their phase distribution in crystalline fraction. However, in spite of being a convenient tool for the brakes NEE phase composition investigations, XRD probe suffers of two following main drawbacks: *i)* poor detection limits of analytes, especially when limited amount of material is available for the analysis or nanometric particles are investigated; and *ii)* complete insensibility to amorphous materials. Considering the aforementioned reasons, this contribution proposes X-Ray Absorption Near Edge Structure (XANES) as additional analytical probe for widening the field of inorganic compounds speciation in brakes NEE. As case study, authors report on the speciation of Ti, V, Cr, Mn, Fe, Ni, Cu, Zn and Sn -based compounds contained in brakes NEE generated by the coupling of a grey cast iron (GCI) brake disc and ECE R90 low metallic brake pads, representing the current standard of friction pairings in the EU market. Brakes NEE investigated in this study have been collected in both micrometric and nanometric dimensional fractions, during tests carried out at a variable inertia brake dynamometer bench following the most updated guidelines reported in the United Nations Global Technical Regulation (UN GTR) n°24 for laboratory measurements of brake emissions for light-duty vehicles.

Acknowledgments

This work was supported by the European Commission's Horizon 2020 research and innovation program, nPETS (grant agreement No 954377, https://www.npets-project.eu/), aimed at studying the sub-100 nm particles emitted from different transport modes.

Ultrafine Brake Wear Particles in Real-World Scenarios: Morphology and Composition

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Non-exhaust emissions, such as brake wear particles, are a growing concern due to their significant contribution to urban particulate matter pollution and associated health risks, particularly from ultrafine particles that can penetrate deeply into the respiratory system [1, 2]. These emissions, influenced by the thermal and mechanical conditions of braking, require further investigation to better understand their environmental and health impacts [3].

This study aims to bridge the gap between laboratory and real-world analyses by developing an innovative approach that combines in situ and off-line particle characterization. On-road tests were conducted with a passenger vehicle under harsh braking conditions (60–120 km/h), achieving disk temperatures of up to 380 °C. Real-time measurements using an Engine Exhaust Particle Sizer (EEPS) revealed significant concentrations of ultrafine particles during high-temperature braking events. Off-line analyses using Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray Spectroscopy (EDS) provided detailed insights into the morphology and elemental composition of the particles. Additionally, Transmission Electron Microscopy (TEM) was employed to explore their nanoscale structure.

The results highlight the dependence of particle size and morphology on brake disk temperature, with thermal decomposition processes leading to smoother, more spherical particles at higher temperatures. These findings are particularly relevant for scenarios such as descending steep downhill roads, where prolonged braking heats the system significantly before entering urban areas, amplifying emissions. This work underscores the importance of combining real-time and microscopic analyses to advance the understanding of brake wear particles and their environmental implications

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Assessment of Airborne Emissions from Tire Wear: Insights into Ultrafine Particle Distribution

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Since tire wear is one of the largest sources of microplastics in the environment today, its measurement and mitigation are of significant public and regulatory interest. Tire wear is regulated in terms of the weight loss of a tire over distance traveled. This is currently the primary focus of the UNECE Task Force on Tyre Abrasion (TFTA). However, the airborne fraction of tire wear is not considered by the TFTA and remains unknown.

Due to the presence of background emissions in real-world driving (brake wear, exhaust emissions, road wear, resuspension), the measurement of tire wear particle emissions is challenging. In this study, an outer drum test bench with an enclosure around the tire was used to measure the tire's airborne emissions in a controlled environment. The total particle number (TPN), solid particle number (SPN), particle masses (PM2.5 and PM10), and the size distribution of the aerosols were measured.

Key findings reveal that a high number of particles were in the ultrafine size range, with particle sizes around 10 nm. The results of the total particle number compared to the SPN indicate that most of these particles were volatile, as the TPN was significantly higher than the SPN.

Finally, this study underscores the need for further research in the field of airborne tire wear particles. This research provides a quantification of airborne tire wear particles according to different metrics, helping to understand the potential impact of ultrafine tire particles on human health.

Solar-Thermal Aging of Tire-Wear Particles (TWP) Affecting Their Properties and Environmental-Health Impacts

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Tire wear particles [1] are toxic [2] and produced in large amounts per vehicle km. Cross-disciplinary studies [3] show that they vary in size and composition, containing heavy metals. They are components in toxic water-borne motorway run-off. They have passenger polycyclic aromatic hydrocarbons. Here TWPs have been collected from UK motorways.

Their properties are reported as they undergo solar-thermally aging using TEM, SEM-EDX, XRF, XRD, Raman (sp2:sp3), evolved gas analysis, TPO, DSC, TGA and FTIR methods and how these affect their environmental and health impacts in part by the release of nanoparticles (NPs) and ultrafine particles (UFPs).

This abstract is relevant to NPC-25 Focus Event on Tire Wear Particles

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Reducing Brake Wear Emissions in Public Transport: Insights from the RE_BREATH Project

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Public transport, particularly buses, plays a crucial role in maintaining good air quality in cities by reducing the number of cars on the road and, consequently, the amount of polluting emissions, including non-exhaust Particulate Matter (PM). Within this context, the LIFE program of the European Commission has co-funded the RE_BREATH project, which stands for Reduction of Brake Wear Emissions in the Transport sector. One of the project's objectives is to improve the understanding of non-exhaust particle emissions generated by public transport braking systems.

The study focuses on collecting comprehensive data on PM10, PM2.5, and finer particles through Particle Number (PN) measurements. While extensive research exists on non-exhaust brake emissions from Light-Duty Vehicles (LDVs) with established measurement protocols, there is a significant gap in focus on Heavy-Duty Vehicles (HDVs). To address these challenges, the study is structured into four distinct phases:

1. Instrumentation and Data Acquisition: This phase involves equipping an HDV with the necessary instruments to collect data and acquire essential mission profile information.
2. Analysis of Mission Profiles: In the study, typical mission profiles of HDVs are analyzed to understand the conditions under which brake wear emissions are generated.
3. Generation of a Representative Dynamometric Bench Procedure: Based on the mission profiles, a dynamometric bench procedure is developed to simulate real-world braking scenarios.
4. Testing Different Materials: Various brake materials are tested to define emission factors for PM (10 and 2.5) and PN, with a focus on the finer fraction of particulates.

The limitations of the study highlight the need for a more diverse dataset to replicate different scenarios, highlighting the potential for further research and refinement. By addressing these shortcomings, the RE_BREATH project aims to contribute to the understanding and reduction of brake wear emissions in public transport.

Particles Size Manipulation: Experimental and Numerical Study

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This study investigates the efficiency of the particle clustering mechanism ("grouping") under oscillatory flow conditions, utilizing fine particle powder as a representative model for environmental aerosols. The experimental setup incorporates flow oscillations and modular geometries to enhance particle interactions. Continuous particle size monitoring and microscopic analysis of captured particles reveal a shift in size distribution, resulting in the formation of larger aggregates [1].

Additionally, numerical simulations identify two key mechanisms influencing particle dynamics: oscillatory flow parameters and Brownian motion. Particles experience oscillatory flow effects depending on their relative positions within the flow wave, leading to convergence in certain regions and dispersion in others. Furthermore, the stochastic nature of Brownian motion, particularly significant for submicron particles, increases the likelihood of particle collisions and contributes to the observed grouping phenomena. The interplay between deterministic oscillatory forces and random Brownian displacements facilitates clustering within the experimental system's residence time.

Overall, particle manipulation offers opportunities to explore and design methods for enhancing filtration efficiency, improving the detection limits of relevant diagnostic systems and segregating and sorting particles for various applications.

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Minimizing Indoor Infection Risk by Airborne Pathogens with Nanofiltration and Vertical Flow

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The risk of infection between people can be significantly reduced with targeted vertical flow control in the room and nano-filtration of the recirculated air. This cannot be achieved with any other air purification device or ventilation system.

In the work described, three examples of preventing the risk of infection - a classroom ventilation system, ventilation of an elevator cabin and securing a hospital bed - were physically implemented and evaluated experimentally and numerically.

In addition to the results of these examples, the currently applicable regulations were critically discussed, as well as the difficulties involved in the widespread introduction of the innovations developed.

An Innovative Vertical Airflow System with Ceramic Filters for Reducing Airborne Pathogens in Healthcare Settings

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The COVID-19 pandemic underscored the pivotal role of aerosol transmission in the spread of infectious diseases, highlighting the urgent need for enhanced air quality control in healthcare settings[1,2]. In a previous study we have shown that ceramic wall flow filters can be used for an efficient filtration of the virus surrogate MS2 bacteriophages[3]. This study presents a novel vertical airflow device, which integrates the earlier described ceramic wall flow filters to mitigate the spread of airborne pathogens in hospital environments. Positioned above a patient's bed, the system captures exhaled air, filters it through high-efficiency ceramic filters, and redistributes it beneath the bed. Laboratory evaluations conducted in both small (15 m²) and large (36 m²) rooms demonstrated significant reductions in aerosol spread, with filtration efficiencies up to 95% for salt particles and 87% for MS2 bacteriophages under real-world conditions. The system's performance was further tested in combination with hospital curtains, which, while moderately effective on their own, showed marked improvement when used alongside the device. These findings highlight the system's potential to reduce nosocomial infections by lowering bioaerosol concentrations. The combination of vertical airflow and advanced filtration technology offers a practical and effective approach to safeguarding patients and healthcare workers in hospital settings.

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