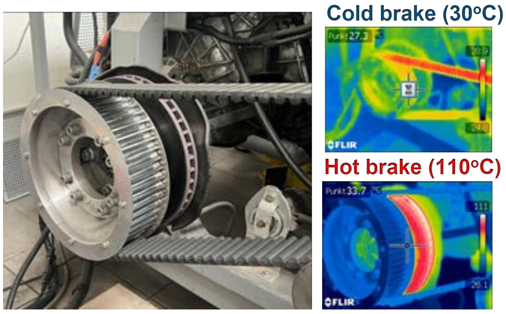
Particle number emissions from brakes of passenger cars

J. Pielecha[1], I. Pielecha[1], J. Sobczak[1]

[1]Poznan University of Technology, Faculty of Civil and Transport Engineering, Poznan, Poland

This article presents the current legal framework and upcoming regulations related to particulate matter emissions resulting from the wear of automotive brake components. Brake dust emissions are a recurring topic in scientific literature due to their detrimental impact on both the environment and human health. Brake dust has been shown to exhibit carcinogenic properties similar to those of exhaust-derived particulate matter. This issue also affects electric vehicles, which are often heavier than internal combustion engine vehicles. When regenerative braking is underutilized, the increased vehicle mass may result in elevated brake dust emissions. Consequently, forthcoming regulations such as Euro 7 will mandate the assessment and limitation of such emissions for both conventional and electric vehicles.



The authors conducted a series of braking scenarios on a specialized test bench, measuring dust emission parameters and determining the mass loss of brake pads after each test. The scenarios varied in terms of simulated initial vehicle speed, brake pedal force (including emergency braking conditions), and pre-established braking protocols. The study included measurements of particulate matter concentration and particle number across various size ranges. The AVL Micro Soot Sensor was used for particulate matter concentration measurements, while a TSI Engine Exhaust Particle Sizer (EEPS) spectrometer was employed to measure particle number and size distribution (covering diameters from 6 nm to 600 nm). The results enabled a qualitative comparison of particulate emissions and an analysis of particle size distribution across different braking conditions. The next phase of the study will evaluate the particle size under similar operating conditions but using various types of friction linings.

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Emission of particulate matter during braking of a rail vehicle on a test stand

L. Rymaniak[1], W. Sawczuk[1], N. Szymlet[1]*

[1]Poznan University of Technology, Faculty of Civil and Transport Engineering

This study addresses the problem of particulate matter emissions released into the atmosphere during the braking process of a rail vehicle tested on a laboratory stand. The experimental tests were designed to replicate real operating conditions. The angular velocities to which the flywheel mass of the test stand was accelerated corresponded to linear vehicle speeds of 160 km/h and 200 km/h. The mass that had to be decelerated by the braking system was 6700 kg.

An EEPS 3090 mass spectrometer was used to measure the particle size distribution and mass of particulate matter generated as a result of friction between the brake pad and the brake disc of the rail vehicle. After each braking cycle, the brake pads were removed from the test stand, weighed, and reinstalled in their original positions.

Figure 1 presents the number concentration of particulate matter emitted in the immediate vicinity of the brake pads for braking speeds of 160 km/h and 200 km/h. The maximum instantaneous particle number concentrations reached 1.62×10^6 #/cm^3 and 4.01×10^6 #/cm^3, respectively. In addition, particle size distributions were determined. For the lower braking speed, the highest particle concentrations were observed in the diameter ranges of 19.1–39.2 nm. For the braking speed of 200 km/h, the highest concentrations occurred in the particle diameter range of 16.5–52.3 nm.

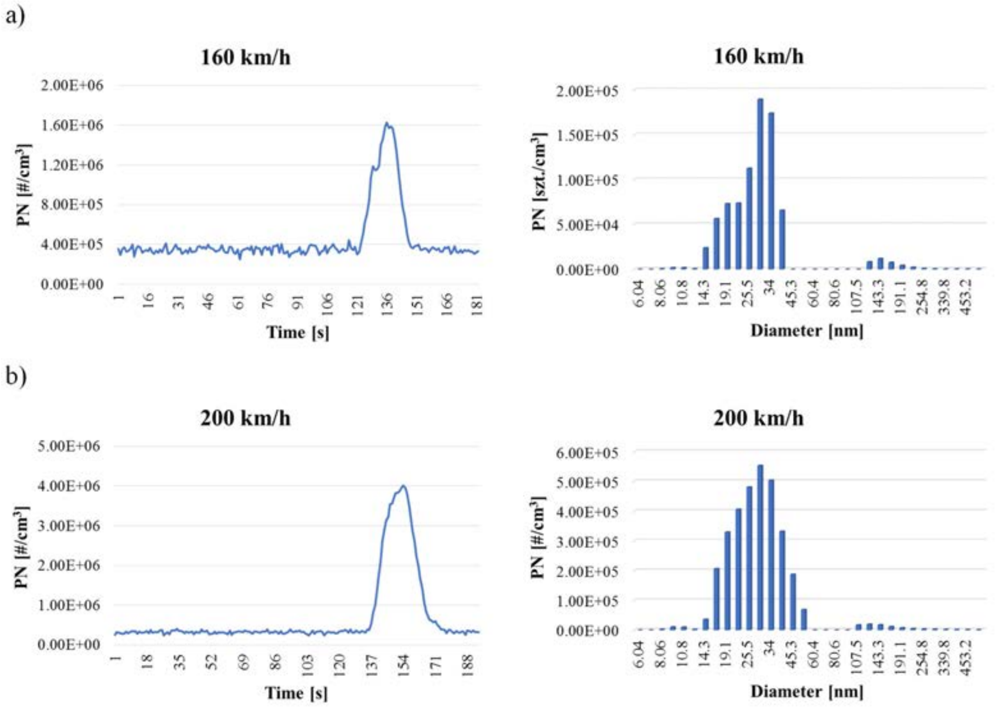

Figure 1. Particle number concentration during the braking process with size distributions for braking speeds a) 160 km/h and b) 200 km/h

Using the spectrometer data, the mass loss of the analyzed samples was determined. For the braking speed of 160 km/h, the mass loss amounted to 187.8 µg, while for 200 km/h it reached 345.6 µg. Measurements of the total mass of the brake pads using a precision balance showed that the overall pad wear during the tests corresponded to 5 g and 11 g for the respective braking speeds.

On-road tire-wear particle emissions from a light-duty vehicle

E. DeFrance[1], Z. Toumasatos[1], G. Karavalakis[1]*

[1]University of California, Bourns College of Engineering, Center for Environmental Research and Technology (CE-CERT),
1084 Columbia Avenue, Riverside, CA 92507, USA

The topic of non-exhaust emissions has received increased attention over recent years due to the continuous reduction of combustion-generated (tailpipe) emissions from mobile sources and their relevance to air quality and health. Current emission regulatory efforts are focusing on reducing particulate non-exhaust emissions that originate from the wear of brakes and tires. Tire-wear particles are small particles abraded from tires during driving due to friction with the road surface and can contribute to ambient ultrafine particle emissions, as well as to PM2.5 and PM10 emissions. This study used a novel sampling system to assess tire-wear real-time particle number, particle size distributions, and gravimetric PM2.5 and PM10 mass from a light-duty truck during on-road driving. . Tire-wear testing was performed on six different tires from five different manufacturers over multiple routes representing urban and highway driving, and concrete and asphalt road pavement. The temperature of the tires was monitored with an IR camera. In addition to the real-time particle measurements, particle morphology for PM2.5 and PM10 was performed by employing a scanning electron microscopy (SEM) with Energy Dispersive X-ray (EDX). Trace elements and metals were analyzed with an X-ray fluorescence (XRF) method, according to US EPA IO-3.3. PM emission samples were also chemically characterized for organic rubber compounds, including N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine (6PPD), 6PPD-quinone, diphenylquanidine,1,3-diphenylurea, 1H-benzotriazole, 2-minobenzothiazole, and many more.

Brake-wear particle emissions measurement and characterization during on-road vehicle testing

E. DeFrance[1], Z. Toumasatos[1], G. Karavalakis[1]*

[1]University of California, Bourns College of Engineering, Center for Environmental Research and Technology (CE-CERT),
1084 Columbia Avenue, Riverside, CA 92507, USA

Brake-wear particulate emissions were assessed during on-road driving with a light-duty vehicle over different routes in the South Coast Air Basin of California. The test routes included a mix of driving conditions, such as highway and urban driving, frequent stop-and-go events, and deceleration events. A novel sampling system was designed to fully enclosed the brake rotor and caliper. The measurement principle was based on the CVS technique in which the airflow rate through the system is held constant. Filtered air was directed into the enclosure and an outlet for the suspended particles was drawn into the onboard sampling tunnel. Emission measurements from multiple brake pads included gravimetric mass for PM2.5 and PM10. PM2.5 and PM10 filters were analyzed for metals and trace elements using the X-ray fluorescence (XRF) method, according to EPA IO-3.3. Real-time PM2.5 emissions were measured with a TSI DustTrak DRX Aerosol Monitor 8534. Total particle number and particle size distribution were made with a Dekati high-resolution ELPI+. In addition to the emission measurements, several thermocouples were used to monitor temperature changes across the brake disc. The results of this study will be discussed as a function of brake disc temperature, driving operating conditions, and brake energy.

Mitigating The Environmental Release of Metal Wear Particles through Sustainable Lubricant

N. F. Mohd Yusof[1,2], S. Ahmad[1,2], C. X. Wai[1,2], Z. Y. Foo[1,2], N. A. Awang[3,2]

[1]School of Mechanical Engineering, [2]Universiti Sains Malaysia, 14300 Nibong Tebal, Penang Malaysia, [3]School of Civil Engineering

Metal wear particles are produced as a result of wear processes and may accumulate in grease-lubricated railway components, including axle bearings and wheel–rail interface lubrication systems [1]. These particles may be released into the environment during leakage and disposal, contributing to soil and water contamination. Particles in grease have been shown to promote surface damage and wear progression in lubricated contacts [2], and wheel–rail interactions also produce airborne wear particles that can contribute to environmental contamination [3].

This study presents a sustainable lubricant strategy aimed at mitigating the environmental release of metal wear particles through source reduction via lubricant formulation. A bio-based grease formulated using palm oil was developed and evaluated against a conventional mineral-based grease. Tribological performance was assessed under boundary contact conditions using a tribometer, focusing on friction behavior, wear response, and wear particle generation. The sustainable grease exhibited significantly lower friction coefficients and reduced wear compared to the conventional mineral grease, indicating improved lubricating efficiency and surface protection.

Wear particle analysis revealed a substantially lower concentration of metal wear particles in the formulated grease, demonstrating effective suppression of particle generation at the tribological interface. Biodegradability was evaluated using Fourier transform infrared spectroscopy (FTIR) and gas chromatography (GC), which showed accelerated chemical degradation of the palm oil–based grease relative to the mineral counterpart. The combination of reduced metal wear particle formation and enhanced biodegradability highlights the potential of the proposed sustainable lubricant to minimize the environmental impact associated with grease waste. This work demonstrates that sustainable lubricant formulation offers a viable pathway for controlling metal wear particles while improving environmental compatibility in heavy-duty machinery applications.

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INDOAIRTOX: Project Overview and Experimental Design for Indoor Ultrafine Particles—Sources, Dynamics, and Toxicity

K. Yeh[1], R. Zhu[1], K. Sharaf Din[1], I. El Haddad[2], R. He[3], B. Rothen-Rutishauser[3], N. Wang[4], J. Williams[4], D. Licina[1]*

[1]Human-Oriented Built Environment Laboratory, Ècole Polytechnique Fédérale de Lausanne, 1700 Fribourg, Switzerland, [2] Paul Scherrer Institute, 5232 Villigen, Switzerland, [3]Adolphe Merckle Institute, Université de Fribourg, 1700 Fribourg, Switzerland, [4]Max Planck Institute for Chemistry, 55128 Mainz, Germany

Inhalation exposure to particulate matter (PM) is known to cause adverse impacts on human health. Much of this exposure is incurred indoors, where people spend the majority of their time. Existing research on air quality and health impacts of PM typically focus on atmospheric fine and coarse particles ($PM_{2.5}$ and PM_{10}, respectively). More recent studies have shifted their focus to ultrafine particles (UFPs), with diameters less than 100 nm.[1] Relative to larger particles, UFPs pose concerns for human health due to their small size and high surface area-to-mass ratio.[2] This facilitates the transport of particle-bound chemicals deep into the respiratory system. Despite the potential for increased adverse health effects from exposure to UFPs relative to larger particles, studies of UFPs of indoor origin remain sparse.

Indoor UFP sources typically fall into three categories: combustion, volatilization/nucleation/condensation (VNC), and oxidation. Various studies have characterized the number concentration of indoor UFPs emitted by different indoor activities such as cooking, heating, and human occupancy.[3-4] However, the composition of UFPs, their dynamics, and the health impacts resulting from exposure to UFP from different sources remains unclear. In this work, indoor UFP sources, dynamics, and toxicity will be systematically investigated using a multidisciplinary approach. A state-of-the-science environmental chamber for controlled UFP generation and transformation experiments will be used, in combination with advanced chemical characterization techniques (PTR-ToF-MS, EESI-MS), and a lung-tissue exposure chamber. This presentation focuses on the project overview and highlights of the experimental design.

Indoor UFP sources of interest include cooking (for different diets, and by different methods), heating, and ozone interactions with emissions from cleaning, human occupants, and personal care products. It is hypothesized that different sources will generate chemically distinct particle populations, producing varying toxicological effects. The impacts of various environmental conditions and building operational settings on UFP formation, dynamics, and lifetime will also be investigated. This unique approach will enable a mechanistic understanding of UFP behavior and toxicity. Findings from this project will improve our understanding of UFP composition, how UFPs from various indoor sources interact with human lung tissues, and inform the design and optimization of building ventilation and air purification systems to minimize indoor UFP exposure.

This study is supported by the Swiss National Science Foundation (CR00-5-239851).

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Particle pollution from ovens in Danish kitchens

R. Bogebo[1], K. Press-Kristensen[1], T. Sigsgaard[2], K. R. Laursen[2], K. B. Johannsen[3], A. Nørgaard[3]

[1]Healthy Indoor Environment, [2]Institute of Public Health, University of Aarhus, [3]Health and Sustainability, Artelia A/S

Background: In developed countries, people spend a large proportion of their lives at home, where smoke from ovens contributes significantly to indoor particle pollution, thereby increasing the risk of cardiovascular diseases, blood clots, lung diseases, cancer, etc. Good kitchen habits and the correct use of efficient cooker hoods or ventilation reduce pollution and the connected risk of morbidity. However, a YouGov survey conducted for Bolius in December 2024 showed that just 12 percent of Danes switch on the cooker hood when using their oven. At the same time, there is a fast rise in the sale of ovens built into kitchen cabinets outside the range of the cooker hood. **Purpose:** The purpose of this study was to perform detailed investigations of particle pollution from cooking food in six traditional ovens under cooker hoods and six ovens built into kitchen cabinets (not under hoods) in Danish kitchens. **Methods**: Particles (PN and $PM_{2.5}$) were measured with calibrated P-Traks and DustTraks from TSI in 12 Danish kitchens. Before measurements, ovens were cleaned and the efficiency of the cooker hoods were tested. No other pollution sources were active during the measurements. A reproducible standard frying setup preparing two pieces of bacon in the oven was used under the following three test conditions: a) not using the hood, b) using the hood at the highest level, c) using ventilation (through draught versus open kitchen window). **Results:** For ovens placed under cooker hoods, efficient hoods and ventilation with through draught are roughly equally effective at removing PN pollution, while the hoods are more effective than ventilation with just the kitchen window open. Efficient hoods are better than ventilation at removing $PM_{2.5}$. For ovens not placed under kitchen hoods (ovens built into kitchen cabinets), ventilation can be the most efficient method for removing both PN and $PM_{2.5}$. Frying two pieces of bacon under standard conditions in an oven without the use of a cooker hood or ventilation can contribute more than 20 times as much to the pollution with PN and $PM_{2.5}$ in the kitchen as the local traffic contributes to the pollution on the most polluted street in Copenhagen during rush hours. This is because most diesel cars have particulate filters and pollution from traffic is diluted in a large volume of air, while the smoke from the oven is concentrated in the kitchen if no hood or ventilation is in use. Significantly higher pollution levels would be expected when the oven, baking trays etc. are not cleaned properly, and more than two pieces of bacon are cooked. The pollution spreads to the rest of the home if the kitchen door is left open. **Conclusion:** This study confirms that pollution from using ovens without using cooker hoods or ventilation will expose Danes to high levels of PN and $PM_{2.5}$ pollution. Exposure can be reduced significantly if using an efficient cooker hood (especially for ovens placed under a cooker hood) or ventilating during cooking. Through draught is generally more efficient in removing particle pollution than just an open kitchen window. **Perspectives:** There is an urgent need for much more information on the importance of using an efficient cooker hood, or at least ventilation, when cooking in ovens, in order to prevent health damaging pollution in Danish homes. The Danish Building Code should include specific requirements to improve public health by reducing particle pollution from cooking. Finally, requirements are needed to ensure that key pollution sources, such as ovens, are placed under effective hoods when installing new kitchens and when changing ownership of homes. **Acknowledgement:** This study is funded by the philanthropic organisation Realdania.

Distinguishing Total and Solid Particle Emissions from Household and Office Devices using a Catalytic Stripper

P. S. Bauer[1], A. Topuz[1], V. Berger[1], M. Dollner[1], H. Schulz[1], A. Boies[1,2]*, J. Swanson[1,3]*

[1]Catalytic Instruments GmbH & Co.KG, 83026 Rosenheim, Germany, [2]Stanford University, Department of Engineering, Stanford, CA 94305, United States, [3]Minnesota State University, Mankato, MN 56001, United States

People spend most of their time indoors, where they are exposed to a very complex mixture of aerosol. Their size and chemical composition depends on various factors, e.g. the room, furniture, and activity of the people and can range from ultra-fine particles (UFPs) to coarse mode aerosol. Especially household appliances which produce heat, such as toasters, hair driers [4], and also printers [3], are prone to generate a large number of particles. Most of the UFPs produced are semi-volatile organic compounds (SVOCs) [4], but, e.g., a toaster can be seen as a hot wire generator, which also produces solid (metal) particles.

A catalytic stripper (CS) is commonly used to separate the volatile and semi-volatile fraction of the aerosol from the solid aerosol part [5]. It has the advantage over a normal thermal denuder that the volatile substances get catalytically transformed and cannot condense again into particles after the treatment. The CS has successfully been used in many Particle Measurement Programme (PMP) compliant studies [1, 2, 5], however not in many indoor aerosol studies, where this simple distinction between volatile and solid particles might also be an important factor for health and mitigation strategies.

Here we present various studies on household and office devices, where we used a CS to determine the amount and size of solid and semi-volatile particles. One example is the printer, which has important implications for home and work place air quality. For example, a laser printer was placed in a box with particle-free air supply. The solid and total particle number concentration was monitored with two condensation particle counters (CPCs) with or without a CS, respectively. The printer produced already particles before the actual printing process started with concentrations going beyond $10^5/\text{cm}^3$. About 97% of the particles are from SVOCs. Another example is the toaster, where about 98% of the particles were solid.

These examples demonstrates the simplicity of distinguishing between solid and volatile particles using the CS, which is also possible for other indoor aerosol sources. This information could help to develop new mitigation strategies and foster future particle emission regulations for household and office devices.

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Comparative analysis of particulate matter emissions from 3D printing and the internal combustion engine

N. Szymlet[1], L. Rymaniak[1]

[1]Poznan University of Technology, Faculty of Civil and Transport Engineering

The aim of the study was to compare particulate matter emissions in terms of both concentration and number during the operation of a 3D printer and a motor vehicle. The research objects included a desktop 3D printer with a closed chamber and no filtration system, as well as a passenger car equipped with a spark-ignition engine. For comparison purposes, the printing process of a carabiner using black ABS filament was analyzed, while the vehicle was driven under real operating conditions on urban and suburban roads. The highest intensity of particulate matter emissions during the 3D printing process occurred at the raft printing stage and at the initial phase of the actual printing. In the case of passenger car operation, particulate emissions were strongly dependent on driving conditions, with the highest values recorded during rapid vehicle acceleration. When comparing both research objects, it can be assumed that, in quantitative terms, the number-based particulate matter emissions generated during a 1 km drive in a modern passenger car are equivalent to those produced by four 3D printers operating continuously for one hour.

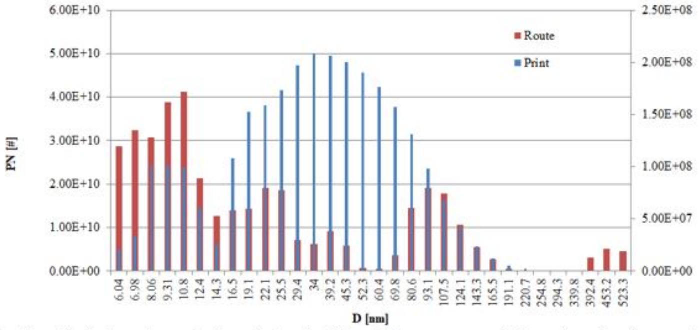


Figure 1. Total particulate matter emissions during the 3D printing process and internal combustion engine operation.

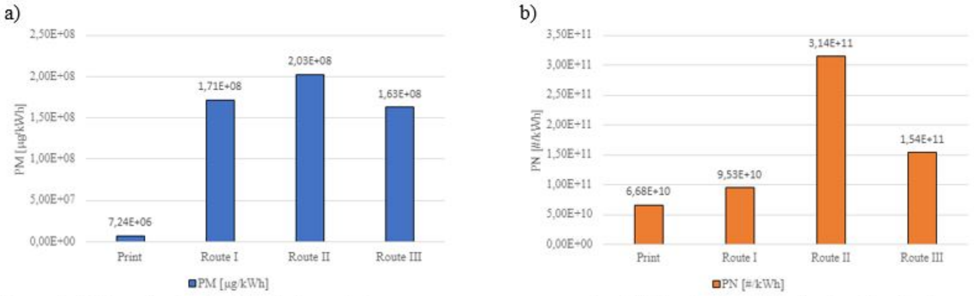


Figure 2. (a) Mass distribution of emissions relative to process energy consumption; (b) Number-based distribution of particulate emissions relative to process energy consumption

A tendency toward increased concentrations of particulate matter in poorly ventilated indoor environments without additional air filtration poses a significant health risk. Given the growing popularity of desktop 3D printers among home users, further research is recommended. Future studies should include a wider range of materials used in additive manufacturing and assess the influence of environmental conditions—such as air humidity and filament properties—on the health risks associated with individual use of 3D printers.

Particle Number Concentration and Size Distribution in the Cabin of a Light Aircraft during Real-World Flight Operations

R. Jasiński[1]

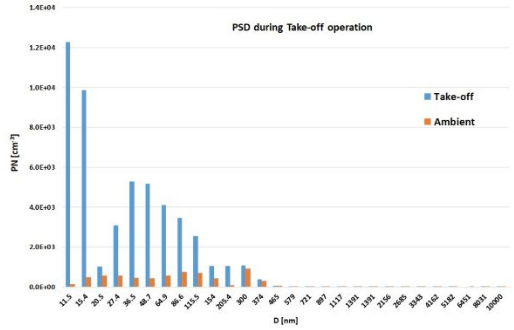
[1]Poznan University of Technology, Institute of Powertrains and Aviation

People spend a significant portion of their time in enclosed environments, including vehicle cabins, where exposure to airborne particulate matter may pose health risks. While indoor particle concentrations have been extensively studied in buildings and ground vehicles, data for small aircraft cabins remain scarce. This study investigates particle number concentration and size distribution inside the cabin of a light aircraft (Cessna) under real operational conditions.

Measurements were conducted during several dozen flight hours using a portable aerosol spectrometer, covering a wide range of flight phases and maneuvers, including taxiing, take-off, climb, cruise, descent, and landing, as well as selected dynamic maneuvers. Particle number concentrations and size distributions in the submicron and ultrafine particle ranges were continuously recorded and analyzed in relation to flight phase, engine operating conditions, cabin ventilation settings, and aircraft dynamics.

The results reveal pronounced variability in particle concentrations depending on flight phase, with elevated levels observed during ground operations and specific in-flight maneuvers. Changes in particle size distributions suggest differing source contributions, including infiltration of outdoor air, engine-related emissions, and resuspension processes induced by aircraft motion and airflow patterns within the cabin. The findings highlight the influence of ventilation effectiveness and operational parameters on passenger and pilot exposure.

This study provides one of the few comprehensive datasets on particulate matter in small aircraft cabins and contributes to a better understanding of indoor air quality in aviation environments. The results may support the development of targeted mitigation strategies, including improved ventilation and filtration solutions, to reduce particle exposure in general aviation.



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Industrial Waste Derived Filtration Systems for Mitigating Indoor TVOC Exposure from Household Cooking

A. Lawrence[1]

[1]Department of Chemistry, Isabella Thoburn College, Lucknow, India

Indoor air pollution from biomass based cooking remains a major public health concern in rural households, where women experience disproportionately high exposure to total volatile organic compounds (TVOCs). This study investigates the performance of a cascaded industrial waste derived filtration system designed to sequentially remove TVOCs emitted during typical household cooking. The system integrates three low-cost, sustainable layers i.e. a coconut husk mat (macro-porous), fly ash based porous pellets (meso-porous), and electrospun nanofiber mats (nano-porous). Laboratory experiments were conducted using a glass exposure chamber linked to a traditional mud chulha, and parallel onsite trials were performed in rural households. TVOC concentrations before and after filtration were measured using a BR-SMART VOC analyzer to determine removal efficiency, adsorption capacity, kinetic constant (k), and temporal decay behaviour. Five composition coconut husk, fly ash pellets, nanofiber mat, fly ash + nanofiber, and the full tri-layer system were evaluated. Laboratory removal efficiencies ranked as follows: tri-layer (83.51%), fly ash + nanofiber (80.73%), nanofiber (59.0%), fly ash pellets (48.90%), and coconut husk (34.01%). Onsite measurements showed similar stratification with slightly lower values (78.12%, 73.40%, 46.8%, 41.2%, and 26.8%, respectively), reflecting environmental variability. Response Surface Methodology (RSM), contour plots, and wireframe decay curves demonstrated that adsorbent mass, initial concentration, pore structure, and adsorbed mass strongly influence removal dynamics. Pearson correlation analysis identified the kinetic constant k as the dominant driver of TVOC reduction under both laboratory and field conditions ($r \approx 0.95$), whereas adsorption capacity exhibited weak correlation due to short exposure duration. The cascaded multilayer design exhibited synergistic behaviour by coupling macro-, meso-, and nano-scale adsorption mechanisms, enhancing mass transfer, surface interactions, and breakthrough resistance.The findings confirm that combining natural biomass materials with industrial waste derived adsorbents and engineered nanofibers provides an effective, adaptable, and economically viable solution for reducing women’s indoor exposure to hazardous VOCs in biomass-dependent rural communities.

A new instrument to examine the oxidizing properties of polluted air in both the gas and particle phases (GP-OOPAAI)

E. Chamot[1], M. Harder[1], K. Y. Cheung[1], B. Utinger[1], M. Kalberer[1]*

[1]Department of Environmental Sciences, University of Basel, Basel, 4056, Switzerland

The complexity of the air's composition makes it difficult to identify which compounds are most harmful. To assess the influence of atmospheric composition on human health, the oxidative potential (OP) represents a key metric, as it reflects the capacity of particulate matter to generate reactive oxygen species (ROS), which play a central role in oxidative stress and related biological responses in the human body. An imbalance between ROS or other exogenous oxidants and antioxidants leads to oxidative stress, which contributes to the development of various diseases. OP has recently been proposed as a new parameter to be measured at air monitoring stations across Europe in the new European Air Quality Directive. Numerous studies have focused on OP generated by particulate matter (PM), which has been proven to have significant impacts on human health [1]. However, gaseous pollutants in the air — such as NO□, SO□, O□, and reactive organic gaseous compounds — also contribute substantially to the production of ROS [2].To better understand the combined oxidative impact of both phases, it is necessary to develop analytical instruments capable of measuring the oxidative potential of gases and particles simultaneously and with high time resolution to capture the highly dynamic changes in atmospheric composition. Over the past two decades, several antioxidants have been used for OP measurements, the most common being DCFH, DTT, and AA (ascorbic acid). Among these, AA is often preferred because it is a naturally occurring antioxidant in the human lung, making it particularly relevant for representing real biological oxidation processes. Recent developments have enabled online measurements of the oxidative potential of the particulate phase as characterized with AA in ambient air with a time resolution of a few minutes [3].

In this study, a new instrument is being developed to measure online the oxidative potential of both the gas and particle phases of ambient air, using a Metrohm AeRosol Sampler (MARS) and ascorbic acid (AA). The objective is to develop an analytical method capable of estimating the oxidizing properties of polluted air in both phases. Air is sampled using the MARS system, where an ascorbic acid (AA) aqueous solution is constantly pumped through a wetted wall annular denuder. This setup enables the transfer of reactive gaseous molecules into the liquid phase, where they react with AA to form dehydroascorbic acid (DHA). Particles are not retained in the denuder but are collected separately in a PILS unit behind the denuder in an AA solution. The concentration of DHA (indicating the amount of AA oxidized by gases and particles) are then separately mixed with o-phenylenediamine (OPDA). DHA reacts with OPDA to form 2,3-dihydroxyfluorene (DFQ), a fluorescent compound. Finally, by measuring the fluorescence intensity of DFQ, the oxidative potential of the air sample can be quantified in the gas and particle phase. Flow characteristics of the AA solution in the denuder and the reaction efficiency of the AA towards NO2, O3, and gaseous peroxides are being determined to characterize the response of oxidizing gases in relation to the overall OP of a polluted atmosphere.

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Comparing effects of freshly generated brake wear particles with particles collected on Teflon filters in an advanced in vitro lung model

L. Path[1], G. Gunasigam[1], N. Jung[1], J. Becker[2], C. Neukirchen[3], T. Adam[3], S. Di Bucchianico[2], A. Petri-Fink[1]*, B. Rothen-Rutishauser[1]*

[1]Adolphe Merkle Institute, University of Fribourg, Fribourg, Switzerland, [2]Institute of Chemistry, Department Life, Light &Matter, University of Rostock, Rostock, Germany, [3]University of the Bundeswehr Munich, Faculty for Mechanical Engineering, Institute of Chemistry and Environmental Engineering, Neubiberg, Germany

Non-exhaust emissions have gained increasing attention in light of the upcoming Euro 7 regulation for vehicles, which defines maximum particulate matter (PM) emission factors for tire and brake wear. PM ≤ 2.5 µm (PM2.5) is of special interest since it can enter, deposit and accumulate deep in the lungs where it can lead to inflammatory reactions. To analyze brake dust more in depth, a custom-built brake dyno was used to generate brake wear emissions [1]. Chemical analysis of the brake dust revealed highly metallic content with > 50 % of PM2.5 emitted as iron and other heavy metals in varying concentrations depending on the brake pad used. Particles from low-metallic brake pads were produced under real-world conditions and directly exposed to lung cells, as well as collected in parallel on Teflon filters. Direct exposure to a 3D lung cell model composed of bronchial epithelial cells (Calu-3), endothelial cells (EA.hy926), and macrophages (THP-1) resulted in a dose-dependent increase of cytotoxicity, and other endpoints are currently being analyzed. In this study, we extracted the particles collected on Teflon filters to compare the effects of direct particle exposure. Total particle mass that was extracted from the filters was determined by means of a Quartz Christal Microbalance. Scanning Electron Microscopy was used to compare the morphology of filter-extracted particles with the freshly generated particles and the morphology of the particles was similar. Preliminary 24-hour exposure experiments under quasi-ALI conditions to extracted brake wear particles indicate dose-dependent cytotoxic effects (LDH release). Particles may potentially cause disturbed membrane integrity (TEER), as well as release of inflammatory cytokines (IL-8).

The effects of direct brake wear particle exposures with particles collected on Teflon filters will be compared, including a particle deposition calculation.

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Photoacoustic spectroscopy for ambient black carbon monitoring

J. Murg[1], P. Kotnik[1], H. Reingruber[1], M. Arndt[1], B. Tschofenig[2]

[1]AVL List GmbH Hans-List-Platz 1, 8020 Graz, [2]Office of the Styrian Provincial Government, Landhausgasse 7, 8010 Graz

Black carbon (BC) is an important air pollutant produced by combustion processes such as road traffic, industrial activity, and residential heating. It is included in the European Ambient Air Quality Directive (EU 2024/2881), highlighting the need for reliable BC measurements at low ambient concentrations. Filter-based Aethalometers are widely used for ambient BC monitoring. Their measurement principle is based on the attenuation of light transmitted through a particle-loaded filter. As a result, BC absorption is not measured directly but is derived using empirical correction factors to account for filter loading effects, multiple scattering, and instrument-specific calibration assumptions. Photoacoustic spectroscopy (PAS) provides a filter-free alternative by directly measuring the light absorption of BC particles in situ. In this study, PAS was applied with high accuracy using the AVL Black Carbon Monitor for ambient air measurements. The instrument allows time-resolved BC measurements in the nanogram per cubic meter range and is suitable for long-term use in urban environments. The AVL Black Carbon Monitor operates at multiple optical wavelengths, enabling the calculation of wavelength-dependent absorption coefficients and the absorption Ångström exponent (AAE). These parameters provide quantitative information on the spectral dependence of BC absorption and can be used to support source apportionment by differentiating contributions from fossil fuel combustion and biomass burning. Field measurements were carried out at several urban monitoring sites in the city of Graz, Austria, covering locations with different traffic influence and residential emission characteristics. The measured BC data show temporal changes and spatial differences consistent with varying urban emission conditions. This work shows that PAS-based BC measurements are a useful alternative to established filter-based methods for ambient air quality monitoring and emission assessment.

Thermally stable and spherical silver particles as transfer standard for the calibration of particle number counters

A. Nowak[1], A. Makelko[1], J. Roshal[1], M. Dollner[2], V. Berger[2], P. S. Bauer[2], H. Schulz[2]

[1]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, 38116, Germany, [2]Catalytic Instruments GmbH & Co.KG, 83026 Rosenheim, Germany

Particle number concentration is one of the key physical parameters targeted by several vehicular emissions regulations [3, 4, 5, 6], and ambient air quality guidelines [1, 2]. Different calibration aerosols, such as solid soot, emery oil, and silver particles, are used to calibrate particle number counters in terms of counting efficiency and linearity. However, this leads to a lack of comparability of the results. For calibration facilities it is crucial to have a stable and well-characterized aerosol source that produces solid, inert, insoluble, and thermally stable spherical particles. Silver particles generally satisfy all of these requirements. PTB and Catalytic Instruments are working closely together to optimize the Silver Particle Generator (SPG) to fulfil a broad spectrum of calibration protocols, e.g., for ambient and automotive specifications. The goal is to establish a calibration aerosol that could serve as transfer standard across different communities.

Since October 2025, several tests have been performed at PTB to investigate the long-term stability and day-to-day variability of the SPG. At one operating point the Geometric Mean Diameter (GMD) (at 6 nm) exhibits an apparent long-term stability of approximately 0.5 nm over two months. During this time, fluctuations in particle size were observed to correlate with variations in ambient pressure. In addition, the SPG settings will be optimized to fulfil the CEN-CPC calibration protocol for linearity and counting efficiency testing. An initial CPC calibration test was performed by varying the SPG temperature, demonstrating good stability, a straightforward setup, and minimal time effort. The smooth operation of the SPG is the ability for controlling the heater temperature in precise 1°C steps that allows a stable production of narrow size distributions of spherical silver particles but also enables the ability to shift these distributions.

With this project we will demonstrate the feasibility of producing spherical silver particles beyond 100 nm in diameter. This provides the basis to establish a harmonized calibration standard across different communities. Next to the improvements of the SPG performance, a PTB-developed dilution unit and a coagulation chamber will be optimized to guarantee spherical silver particles at high concentrations even beyond 100 nm.

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[1] Directive (EU) 2024/2881 of the European Parliament and of the Council of 23 October 2024 on ambient air quality and cleaner air for Europe, [2] EN 16976 (2024) Ambient air - Determination of the particle number concentration of atmospheric aerosol; German version, [3] UN Regulation No 168 (2024/211) – Uniform provisions concerning the approval of light duty passenger and commercial vehicles with regards to real driving emissions (RDE), [4] Directive (EU) 2024/2881 of the European Parliament and of the Council of 23 October 2024 on ambient air quality and cleaner air for Europe, [5] Nr. 133 Richtlinie zur Kalibrierung von Abgasmessgeräten, die für die Untersuchung der Abgase von Kraftfahrzeugen nach Nummer 6.8.2 der Anlage VIIIa StVZO eingesetzt werden („AU Geräte Kalibrierrichtlinie“), Absatz 3.2.5. Fassung vom Mai 2021,

[6] PTB-Anforderungen 12.16 „Partikelzähler“ (05/2021). Physikalisch-Technische Bundesanstalt, Braunschweig und Berlin. DOI: https://doi.org/10.7795/510.20210623

Traceable Calibration of MPSS in Fast-Scan Mode: Recommendations for Particle Number Size Measurement at Urban Traffic Hot Spots

A. Malik[1], J. Rosahl[1], S. Platzler[1], A. Nowak[1]*

[1]Airborne Nanoparticles (WG: 3.43), Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, 38116, Germany

Ultra fine particles (UFPs), owing to their documented health impacts and the Euro 7 revision (lowered particle-size threshold from 23 nm to 10 nm), have emerged as pollutants of primary concern. Consequently, to better represent real-world emissions there is a growing emphasis on measuring solid and total (solid + volatile) UFPs by establishing the monitoring networks strategically located near transport-related emission hotspots. Currently, the UFPs are monitored in Europe as part of particle number and size distribution (PNSD) measurements over the range 10-800 nm by using a mobility particle size spectrometer (MPSS). The associated quality assurance procedures are standardized by CEN/TS 17434:2020, which prescribes validation of a calibrated MPSS (to be deployed for the field measurements) against a reference MPSS (measuring PNSD) and CPC (measuring Particle Number i.e., PN_{CPC}) over this full scan range using ambient aerosol. However, this wide scan range is not ideal for measurements at urban traffic sites where the PNSDs typically peaks around 50-70 nm with negligible number above 300 nm. Specifically, the long scan time required for full-range measurements leads to degraded temporal resolution limiting detection of transient events such as passing of high-emitter vehicles. Moreover, the calibration using ambient aerosol may not represent traffic-related emission characteristics adequately.

To address these gaps, this study put forward an evolved calibration and validation procedure specifically designed for the PNSDs measurements at urban traffic sites. For validation and compliance with the existing norms, the performance of a candidate MPSS (the reference MPSS at PTB) is evaluated as per this modified procedure. The MPSS is evaluated under fast-scan mode (1 minute scan time and scan range 10-300 nm) using the lab generated solid/total soot PNSDs with varying operating points (Geometric Mean Diameters ~ 30-90 nm and PN_{CPC}: 10,000 – 90,000 cm^{-3}). Moreover, a comparatively traceable and flexible uncertainty budget scheme (incorporating uncertainty dependency on the parameters of test aerosol) is proposed based on existing literature and the experimental observations.

The repeated long-term DMA calibrations results confirmed that the mobility diameters measurements by reference MPSS are reproducible to be within ±3 % of the certified PSL diameters. Moreover, the cumulative PN measured by the reference MPSS (PN_{MPSS}) remained within ±5% of the PN_{CPC} measured by a parallelly running reference CPC. The uncertainty limits of the reference MPSS for particle number (PN) per size bin at a nominal PNSD ($PN_{CPC} \approx 30{,}000$ and $D_{P,\ MEAN} \approx 60$ nm, approx. representative of traffic site conditions) were also within the CEN (≤50% below 20 nm, ≤10% in the range 20-200 nm, and ≤20% above 200 nm) criteria. Above findings implies that the reference MPSS fulfils all the existing CEN criteria for a reference MPSS confirming its usability for the subsequent validation of the test MPSS under fast-scan mode and lab generated soot particles. Consequently, a modified MPSS calibration procedure has been implemented at PTB, featuring a 1-minute scan time, a scan range of 10–300 nm, and soot particles as the test aerosol. Furthermore, the investigations in current study highlights that the uncertainties in PNSD measurements by a MPSS can be higher that the CEN criteria under specific conditions such as DMA operating with high-voltage negative polarity or when PN_{CPC} are low. Consequently, a modified criteria in the form of well-established E_n-score metric is proposed for validation of test MPSS calibrated at PTB.