Assessing the Impact of Emissions from Zürich Airport on Ultrafine Particles and Volatile Organic Compounds in a nearby Residential Area

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Civil aviation and airports are major urban sources of Ultrafine Particles (UFPs) and Volatile Organic Compounds (VOCs)[1]. UFPs are a concern because their small size (<100 nm) allows deep lung penetration and associated health risks. The aviation emission profile from the USA's Environmental Protection Agency includes 15 hazardous VOCs of which many are carcinogenic Polycyclic Aromatic Hydrocarbons (PAHs)[2]. VOCs can act as precursors to secondary organic aerosols and low-volatility VOCs can condense on particles, altering their properties. To characterize UFPs and VOCs emissions from aviation, two intensive one-month measurement campaigns of gaseous and particulate matter were performed in November 2022 and August 2024, 1 km downwind of Zürich Airport. The results indicate that high UFP number concentrations up to 300 000 cm^{-3} originate solely from aircraft operations, as shown by the similar diurnal profiles between air traffic movements and UFPs concentrations in Fig. 1a. These emissions are either advected downwind of the airport or mixed downward during aircraft landing overpasses. Using Positive Matrix Factorisation (PMF) on the VOCUS Proton Transfer Reaction Mass Spectrometer (PTR-MS) data, a factor containing naphthalene species and several alkanes with m/z > 100 (Fig. 1 c) has been attributed to VOCs aviation-related emissions. This is further supported by the co-increase of its time series with UFPs temporal evolution (Fig 1.b). However, when the site is not downwind and under the influence of landing overpasses, only UFPs concentrations increased, rather than the VOCs aviation-related factor (Fig. 1a), highlighting landing overpasses as a major source of UFPs but not of VOCs. This contrast likely results from lower engine thrust during taxiing at the airport than during landing overpass, which produces more VOCs due to reduced combustion efficiency[3]. At this stage, we cannot exclude a contribution of VOC emissions from engine refuelling. Future work will investigate the formation and evolution of VOCs in aviation plumes and their potential role in UFPs formation and growth. The widespread presence of UFPs and the co-emission of VOCs poses health concerns for communities near airports that should be addressed.

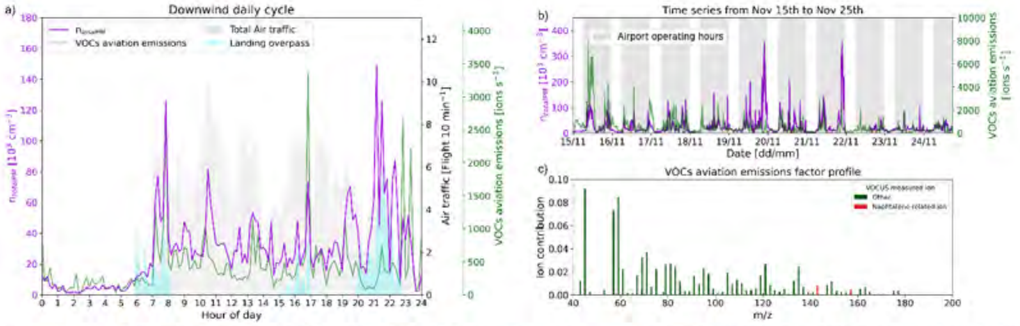

Figure 1: a) Diurnal cycle of air traffic at Zürich airport, UFPs number concentration $n_{totalPM}$, and VOCs aviation emissions when the measurement site was downwind of the airport during the fall 2022 measurement campaign and b) 10-days time series of the same variables. c) Factor profile of the VOCs aviation emissions determined by a source apportionment of PTR-MS data.

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Laboratory-scale Jet Engine Emission Measurements using a Micro Turbojet with Conventional and Alternative Jet Fuel

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Aviation is a growing source of both CO_2 and non-CO_2 emissions. Between 2005 and 2018, aviation fuel consumption increased by 55 % [1], and fuel burn is expected to continue rising as the sector expands further [2]. Strategies to mitigate the associated increase in emissions and their impacts on climate and environment include the adoption of sustainable aviation fuels (SAF). While SAF is reported to reduce CO_2 and NO_x emissions [3], its effects on particulate matter (PM) emissions are more complex as jet fuel changes can alter particle size distributions [4]. Meanwhile, the high production costs and strict safety standards of SAF make experiments using full-scale engines expensive and time-consuming. In this study, we utilized a low-cost micro turbojet test rig to investigate the influence of fuel choice on jet engine performance and emissions.

The test rig included a micro turbojet engine (JetCat P200-SX) with simultaneous performance and emission characterization under repeatable laboratory conditions. The engine was run using two jet fuels: a conventional Jet-A and a Fischer–Tropsch Synthetic Paraffinic Kerosene (FT-SPK) fuel. While FT-SPK does not rely solely on renewable feedstock, it is produced via similar process pathways that could be used for a Power-to-Liquid SAF. Emissions sampling covered gaseous (NO_x, CO, CO_2, TVOC) and PM emissions. PM was measured using a nano Scanning Mobility Particle Sizer downstream of a catalytic stripper (CS) to mimic standardized regulatory aviation non-volatile PM measurement methods. Additionally, TEM samples were collected downstream of the CS for morphological analysis, and samples on quartz filters were collected directly downstream of the engine exhaust to evaluate the soot maturity using Raman spectroscopy. Emission indices were calculated using a carbon balance method.

According to the preliminary results, the mode of the raw measured particle number size distributions shifts toward smaller size ranges by 2 nm when changing the fuel from Jet-A to FT-SPK. When introducing a 50–50 blend of the fuels, the distribution falls systematically between the unblended cases. Thus, the micro turbojet test rig is a promising tool for cost-effectively studying the effects of alternative jet fuels on particulate emissions.

Lintusaari's research visit to UBC was supported by the KAUTE Foundation through the Researchers Abroad program and the GIANT project funded by Business Finland (grant number 5582/31/2023), Helsinki Region Environmental Agency HSY, and several Finnish municipalities and companies. We acknowledge funding by the UBC Clean Energy Research Center (CERC) - the NSERC Discovery Grant Program - the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – EXC 2163/1 - Sustainable and Energy Efficient Aviation and the Impulsfonds der TU Braunschweig, Förderlinie 2: Postdoc International Mobility Grant.

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Characterisation of Emissions from an Inverse Diffusion Burner Relevant to Contrail Formation

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Contrail cirrus and aviation-induced cloudiness form when ice crystals nucleate on exhaust and ambient aerosol particles under ice supersaturation conditions. In situ studies conducted in soot-rich regimes have shown non-volatile particulate matter (nvPM), specifically soot aggregates with diameters around 30 nm, as one of the primary nuclei sources for contrail ice crystals [1]. Microphysical models often approximate aggregate soot as equivalent spheres characterised by an effective diameter (d_p). However, Yu et al. (2024) suggested that soot activation is governed primarily by primary particle size (d_{pp}), rather than by effective aggregate diameter (d_p) [2]. Therefore, accurate representation of d_{pp} and aggregate morphology is required for accurately predicting soot activation fractions and the resulting contrail radiative forcing.

However, experimental data on the activation and ice-nucleating behaviour of surrogate aircraft nvPM are still limited [3]. In this work, we characterise a propane inverse diffusion flame burner as a surrogate source of aircraft nvPM, systematically varying soot geometric mean mobility diameter over an aircraft-relevant range of 8-90 nm by adjusting equivalence ratio (1.0-1.6) and sampling height above the burner (10-25 cm). At a sampling height of 20 cm, the generated soot exhibited mass–mobility exponents (D_{fm}), of 2.1-2.7, measured using a tandem AAC-DMA-CPC configuration. Transmission Electron Microscopy (TEM) was used to investigate primary particle size. These measurements establish a surrogate nvPM source for subsequent ice activation experiments using an expansion chamber.

This work was supported by the EPSRC Centre for Doctoral Training in Aerosol Science.

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The transition to sustainable aviation fuels will lead to reduced contrail ice forming particle emissions

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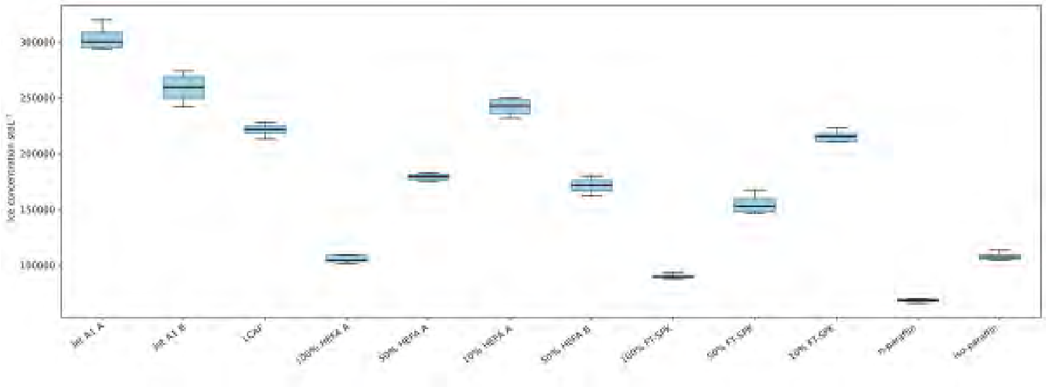
Contrails contribute strongly to the non-CO_2 effects of aviation on climate forcing [1]. Contrails are line-shaped clouds which form behind aircraft as water condenses and freezes onto the aerosol populations emitted by aircraft. They have a strong warming effect by limiting outgoing long-wave radiation and thereby trapping heat. Sustainable aviation fuel (SAF) is a major focus in the aviation industry, aiming to reduce the lifecycle CO_2 emissions of aviation, with many countries having mandated SAF targets. It is important that the use of SAF to reduce CO_2 emissions does not increase contrail formation through differences in the emitted nanoparticles.

Here we present direct measurements of the contrail ice forming ability of jet engine emissions from a variety of SAF pathways and blending ratios. Exhaust from a Honeywell 131-9A Auxiliary Power Unit (APU) burning conventional Jet-A1, SAF from two pathways (Fischer-Tropsch, FT, and Hydrotreated Esters and Fatty Acids, HEFA), and paraffin surrogates was characterized for particle number and size, then sampled into the Portable Ice Nucleation Experiment (PINE) to quantify contrail ice formation. To our knowledge, these are the first direct measurements linking SAF blend fraction, nvPM number and contrail ice nucleation efficiency under controlled engine conditions.

We found that there was an almost tenfold difference in contrail ice forming ability between the fuels with the highest and the lowest ice production, which was in line with the measured change in particulate number concentration. Such a reduction in ice concentration could reduce climate forcing due to contrails by over 50% [2]. We also saw measurable changes in ice concentration from blends with as little as 10% SAF (Figure 1). The different SAF pathways were also measurably different, with the FT fuel producing lower ice concentrations than the HEFA fuel. Despite the small size (20-40 nm) and insolubility of the particles, they were found to activate to ice at close to water saturation for all fuels tested.

These results demonstrate that SAF can reduce aviation climate impact not only through lower lifecycle CO_2 emissions, but also by suppressing contrail ice formation via reduced nvPM emissions. Here we highlight the importance of fuel composition in mitigating non-CO_2 aviation effects.



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Ultrafine particle exposure from individual aircrafts approaching Innsbruck airport

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Aircraft engines emit large numbers of ultrafine particles (UFPs) and carbon dioxide (CO_2) across a wide range of operating conditions, contributing significantly to air pollution. Studies have shown that exposure to UFPs can have adverse health effects, as these particles can enter the bloodstream and act as carriers of toxic substances (1). While there is no guideline level for UFP by WHO, an hourly Particle Number Concentration (PNC) above 20 000 particles/ccm is considered “high” (2). In this work we measured the PNC and CO_2 concentration of individual aircraft emissions on the roof of the Ursulinen school located approximately 1 km east in the extension of the runway of Innsbruck Airport. We carried out long term measurements in 2026 from January through April using portable high-time resolution UFP sensors (Partector2 and Partector2 Pro from Naneos) and a fast CO_2detector (LiCor Li-850). This allows for virtual real-time observations of PNC and CO_2 emissions of individual aircrafts under different meteorological conditions. We observe downmixing of aircraft emissions by the wake vortices of the approaching aircrafts. In the morning PNC and CO_2 are often anticorrelated due to the trapped CO_2 concentrations in the shallow inversion layer. During the day the Boundary Layer (BL) becomes well mixed resulting in positive correlations of PNC and CO_2, which allows to calculate the PNC exposure to humans in the landing corridor created per kg of fuel burned (see Fig. 1). This work was supported by OeAD Sparkling Science (Project Atemluft).

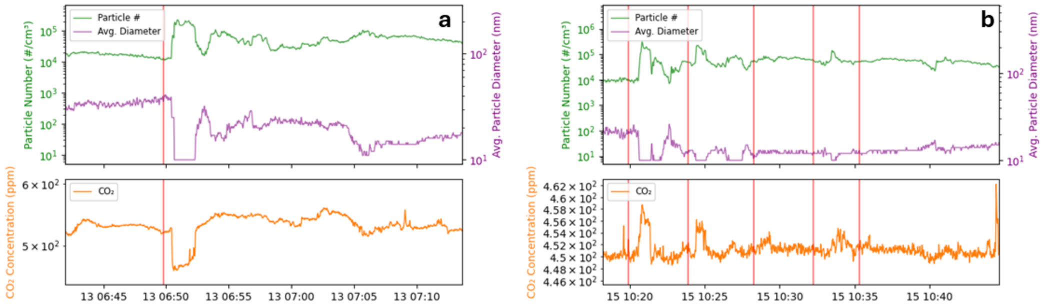

Figure 1: PNC, Average Particle Diameter and CO2 Concentration affected by arriving aircrafts (red lines). **a)** Anticorrelation through BL disruption. **b)** Positive correlations in well mixed BL.

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Ultrafine particle characterization in the near-road environment: association with traffic composition using high time-resolution traffic counts

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Traffic related air pollution (TRAP) is a dominant source of ultra fine particles (UFP) and Black Carbon (BC), especially in densely populated urban areas. Due to the rapid introduction of low- and zero-exhaust emission vehicles around the world, the aerosol particles in the near-road environment are evolving rapidly. The city of Bogotá, in Colombia, which still faces serious air pollution levels, has recently adopted cleaner public policies aiming at improving air quality. Among these efforts, the city has included over 1400 battery electric public transport buses (about 11% of the total), as well as a similar number of CNG public transport buses that had replaced older pre-EURO diesel-power buses. In this work, we report on the characterization of the near-road aerosol particles in a 22 km stretch of a main road where many older buses have been replaced by EV and CNG public transport buses. The main objective is to quantify observable transformation of the near-road exposure to UFP and BC under the recent investments in cleaner transport alternatives. The measurements were carried out from August to November of 2023, both at static sites (on 9 bus stops along the study road) as well as by pedestrians carrying portable monitoring devices. The instrumentation deployed at the bus-stops included devices for determining aerosol size distribution and particle number concentrations (from 10 nm to 10 μm), as well as BC and $PM_{2.5}$. Size distributions were measured with a radial DMA (TSI model 3910) and an optical particle sizer for larger particles (TSI model 3330). Mobile measurements of UFP were carried out with hand-held condensation particle counters (TSI model 3007) and portable aethalometers for BC (AethLabs, model AE51). Overall, we collected personal exposure measurements for pedestrians and cyclists over hundreds of kilometers traveling along the main road. During the sampling period, we also registered traffic counts at 10-second resolution, by analyzing video recordings collocated with real-time particle measurements. Categories for motorcycles, light-duty vehicles, SUVs, and different types of public transport buses (either CNG, EV, or diesel-powered) were also recorded. The geometry of the road was carefully determined to establish an "urban canyon" index. The results of this observational study demonstrated high concentrations at bus-stops, with mean BC concentration of 15.6 $\mu g/m^3$ and UFP number concentration of 64,800 $part/cm^3$ throughout the campaign. For individual days, UFP reached mean values of over 106,000 $part/cm^3$. Similarly high values were observed for pedestrians walking with portable instruments, for whom the average personal exposure concentration was 19.8 $\mu g/m^3$ of BC and 60,400 part $/cm^3$ for UFP. For the analysis, the concentration time-series were decomposed in a slow- and a rapid-varying component. We found a strong association between the fast-varying aerosol field and traffic volume, while the slow-varying part was closely associated with background concentrations and street geometry. Furthermore, our data suggests that the frequency of high BC concentration events can be fully explained by the prevalence of high-emitting diesel vehicles of all types. These events, however, only explain a minor fraction of the observed BC concentration, suggesting that motorcycles and light-duty vehicles are significant sources of BC and UFP in this road. Our measurements clearly show that the efforts to modernize the public transport fleet are still far from enough to achieve an effective reduction in UFP and BC concentrations, particularly in the near road environment. Future studies should analyze the contribution from motorcycles to the near-road aerosol fields, as their use has increased dramatically in the city, which can negate the potential benefits of investing in cleaner public transport alternatives.

Measuring Urban Aerosol Volatility Fractions with a Catalytic Stripper at anACTRIS Aerosol Observatory: Characterization and Implementation

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Aerosol particles play a central role in atmospheric processes, influencing air quality, human health, and climate. To fully understand these impacts, it is essential to quantify not only the physical properties such as concentration or size but also their chemical composition. Offline chemical analysis of aerosol samples or online mass spectrometry are generally complicated or expensive. Another efficient method is to determine the partitioning between the volatile and non-volatile fractions. This information provides insight into the chemical composition of an air mass and allows to infer information about aerosol sources, chemical aging, and transformation processes in the atmosphere [e.g. 1, 2, 3, 4].

A catalytic stripper (CS) is commonly used to separate the volatile and semi-volatile fraction from the solid aerosol particles, which allows for precise measurement of the non-volatile fraction and the total aerosol load [5]. Compared to a thermal denuder, it has the advantage that volatile substances undergo catalytic transformation and cannot recondense into particles after treatment. The CS has successfully been used in many automotive applications such as Particle Measurement Program (PMP) compliant studies [5, 6]. However, not many atmospheric aerosol studies apply this simple distinction between volatile and solid particles, which plays an important factor for the investigation of air quality, human health and climate impact of aerosols.

Here we present the application of a CS for measurements of non-volatile aerosol particles at the Aerosol Observatory of the University of Vienna which is on track to become a National Facility for aerosol in-situ observations within the pan-European Aerosol, Clouds, and Trace Gas Research Infrastructure ACTRIS. This study includes the characterization of the CS with respect to particle penetration and removal efficiency of volatile and semi-volatile components. For particle penetration silver particles were generated with the Silver Particle Generator (SPG) and treated by the Sintering Stage S8000 to obtain thermally stable silver spheres in the size range between 2 nm and 100 nm. The characterization of the removal efficiency of volatile and semi-volatile particles is done with tetracontane, which is a well-established method in many regulations for the testing of volatile particle removal (VPR) systems in the automotive section (e.g. Euro-7).

The aim of this study is to present initial results from continuous measurements of the non-volatile aerosol fraction over several weeks at the Aerosol Observatory in Vienna, demonstrating their potential for source identification and chemical characterization, and highlighting the importance of non-volatile particle measurements.

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Evaluating Traffic-Related Air Pollution Interventions Using State-Space Modelling: Implications for Monitoring and Regulatory Assessment in London.

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Robust interpretation of air quality monitoring data is essential for evaluating the effectiveness of regulatory interventions and supporting evidence-based enforcement strategies. This study applies a state-space intervention modelling framework to quantify the impacts of three COVID-19 lockdown periods (March 2020, November 2020, January 2021) on traffic-related air pollution across London. Daily measurements of NOx, PM_{10}, and $PM_{2.5}$ from 20 monitoring stations (2019–2022) were analysed, covering central London, the Ultra-Low Emission Zone (ULEZ), and Greater London. The model explicitly accounts for temporal autocorrelation, spatial dependence, seasonal variation, ambient temperature, and relative humidity, enabling separation of intervention effects from meteorological and background variability.

Results demonstrate substantial reductions in NOx during the first lockdown (up to 49% in central London), with smaller but significant reductions during subsequent lockdowns. In contrast, particulate matter exhibited heterogeneous responses, including transient increases during the first lockdown, highlighting the complexity of pollutant source dynamics beyond traffic emissions. The modelling framework enabled dynamic estimation of both immediate and progressive intervention effects, providing regulatory-relevant insight beyond conventional before–after comparisons.

The findings offer important implications for interpreting data from regulatory monitoring networks and for evaluating the effectiveness of traffic control measures such as Low Emission Zones and the London ULEZ. By improving attribution of observed concentration changes to policy-driven emission reductions rather than meteorological variability, this approach strengthens the evidentiary basis used in air quality compliance assessment and enforcement decision-making. The study demonstrates how advanced time-series modelling can enhance regulatory evaluation and support more informed air quality legislation and monitoring strategies.

A comprehensive characterization of particles emitted by Internal Combustion Engines using different sampling and analytical techniques.

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Internal Combustion Engines (ICEs) emit micrometric and nanometric particulate matter, which contributes to air pollution and global warming and poses a threat to human health. Technological advances in the combustion process and the introduction of suited particulate filters have considerably reduced, in the last couple of decades, the amount of such particles released in the environment. These advances are certainly encouraging and reassuring. However, a deeper comprehension of the particulate physics and chemistry, at both micrometric and nanometric scales, would greatly help understanding its behaviour both inside the vehicles after-treatment systems (ATSs) and once released in the atmosphere. The present work is aimed at such extensive knowledge of the ICE-emitted particulate behaviour, exploiting several sampling techniques and analytical methodologies such as Transmission Electron Microscopy (TEM), Energy-Dispersive X-Ray (EDX) analysis, Single-Particle Extinction and Scattering (SPES) and Raman micro-spectroscopy to investigate the properties of particles collected at various stages of ICE and ATSs.

Samples were obtained following the guidelines outlined in the European Commission Regulation 1151 (2017) during chassis-dyno driving tests performed under standardized type-approval conditions on various modern diesel- and gasoline-fuelled vehicles. The particulate samples were collected from the engine out, raw and diluted tailpipe exhaust.

A TEM sampler was used to collect samples on carbon-coated copper grids dedicated to TEM and EDX analyses. A MICRO-PSS (Portable Particulate Sampling System) and the PSS on the dilution tunnel of a Constant Volume Sampler (CVS) system were employed for the collection of particles on Quartz-fibre and PTFE-coated glass-fibre filters, to be later investigated by means of Raman micro-spectroscopy. Aliquots extracted from selected filter samples were analysed with SPES. An innovative approach was also explored: single particles identified with Raman were isolated and extracted from the filters, then deposited on TEM grids to perform a correlative TEM analysis.

The results obtained at this stage of analysis show that soot and particulate emitted at the engine-out stage essentially consist of black carbon. However, other types of particles can be detected downstream the ATS, and at different stages of the emission analysis system. For instance, the formation of elongated carbon structures similar to agglomerates of nanorods has been observed by TEM at the vehicle raw tailpipe (after the particulate filter and before the CVS dilution system). CVS-diluted samples, instead, contained, as expected, much fewer particles, essentially consisting of black carbon again. The presented methodology highlights the advantages of combining several techniques to understand the dynamics and reactions of the ICE exhaust in the vehicle and sampling systems. In addition, it paves the way to extensive correlative analyses to be performed with multiple methods (e.g. TEM and Raman) on the same sample to obtain a comprehensive particulate characterization that could be extended to the study of non-exhaust particles such as those from tyre and brake wear.

Field Study On The Abatement Effect Of Particles In Engine Exhaust Of Excavator Equipped With DOC And DPF

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[1]Professor, [2]Student

This study investigated the particulate control efficiency in the engine exhaust of a diesel-powered excavator equipped with a DOC+DPF filtration system under operating modes at a construction site. The excavator has an engine displacement of 5,860 cm3 with a rated power of 110 kW, which has been in service for 15 years. A DOC+DPF aftertreatment system for engine exhaust was employed for 4 years, with both components utilizing cordierite ceramic substrates. The catalytic coating materials include platinum and palladium. The porosity of DOC and DPF are 57% and 37 %, and the mean size of pores is 10~12um and 5~7um, respectively. The filtration system has a cumulative operating time of 220 hours. The diesel fuel used had a sulfur content of 1.4 mg/kg, polycyclic aromatic hydrocarbons (PAHs) at 1.4%, and a cetane number of 53.0. Particle number (PN) concentrations were measured using an optical particle counter paired with a calibration system, which could make real-time measurements through direct exhaust sampling and a dilution device. Particle number concentrations were measured by a TSI DustTrak 8533 monitor. Gaseous pollutants, including CO, NO, and NO2, were detected by using an electrochemical analyzer. Mass concentration of particles was derived by filter samples, which were collected by manual operation following an isokinetic sampling protocol and analyzed in the laboratory. All measurements were conducted under both idling and operating modes of the excavator. The results of the idle mode test indicate that the average PM2.5 concentration in the engine exhaust without control by DOC+DPF was 5.98 mg/m^3. The average concentration decreased to 0.68 mg/m^3 with control devices. The control efficiency of PM2.5 was approximately 89%. The average PN concentration was 1.96 × 106 #/cm^3 and 2.38× 102#/cm^3, with and without control by DOC+DPF, respectively. CO concentrations were 212ppm and 94ppm. The results under excavator operating conditions indicated that the concentration in engine exhaust without DOC+DPF treatment was 190 ppm for CO, 7.53 × 106 #/cm^3 for PN, and 22.7 mg/m3 for PM. The concentration in engine exhaust with DOC+DPF treatment was 6 ppm for CO, 9.36 × 102 #/cm3 for PN, and 0.03 mg/m3 for PM, respectively. Overall, the field measurement results demonstrate that installing a DOC+DPF system on a diesel-powered excavator could significantly reduce emissions of particles and CO in the engine exhaust, respectively.

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Roadside Optical Vehicle Emissions Reporter (ROVER) III Project: Evidence of exhaust tampering in Alberta, Canada

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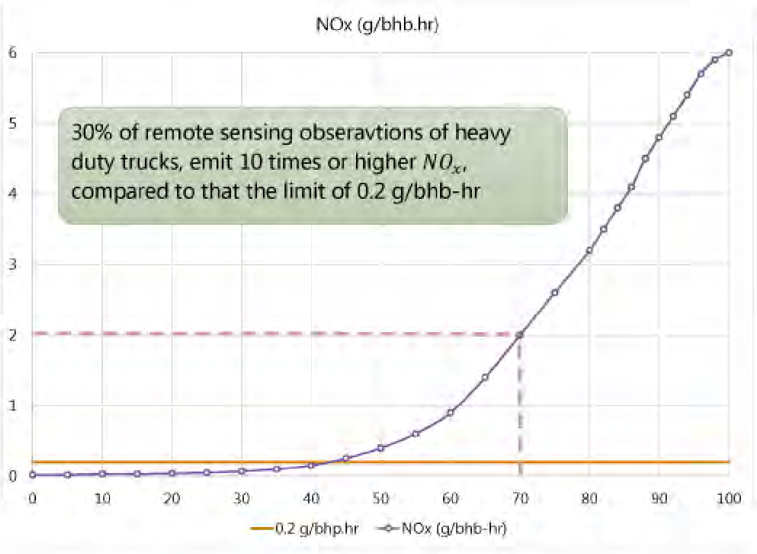
The ROVER III project (2020–2022) used the on-road remote sensing technology to characterize real-world emissions from light-duty gasoline vehicles (LDGVs) and heavy-duty diesel vehicles (HDDVs) across multiple urban centres in Alberta, Canada. Motivated by evidence that a small fraction of vehicles disproportionately contributes to fleet-wide emissions, ROVER III evaluated emission skewness, the prevalence of high emitters, and the in-use performance of modern emission control systems. For LDGVs, vehicles less than 10 years old accounted for more than half of excess HC emissions, suggesting premature deterioration of emission control systems and/or delayed maintenance responses. Light-duty gasoline trucks, particularly pickup trucks, were identified as dominant contributors to HC and NO emissions, with pronounced spatial variability across cities.

For HDDVs, emissions distributions were less skewed but showed widespread exceedances of NOx and particulate matter benchmarks. Approximately 30% of model year 2010 and newer HDDVs exhibited persistently elevated NOx emissions, consistent with malfunctioning or tampered selective catalytic reduction and particulate filtration systems. Among tractor trucks, 38% of model year 2010 -2015 vehicles showed evidence of malfunction or tampering and, despite representing less than one quarter of the fleet, accounted for nearly half of total tractor-truck NOx emissions. Projections indicate that by 2035, such vehicles could increase total NOx emissions by 145% relative to a fully compliant fleet, up to 2.75 times higher than previously forecast. The associated public health burden is estimated at CA$5.4 billion in damages between 2024 and 2035.



30% of remote sensing obseravtions of heavy duty trucks, emit 10 times or higher NO_x, compared to that the limit of 0.2 g/bhb-hr

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Particle number emissions from a Turbulent Jet Ignition engine fueled with hydrogen and ammonia

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Objective of the study was analysis of H_2, NO_x, and particle number emissions using a TJI system under passive and active pre-chamber conditions. Static operating conditions (AVL 5804, 1-cyl; n = 1400 rpm; IMEP = 3.77 bar) were applied for the analysis, covering both passive and active pre-chamber operation (Fig. 1a) with respect to gaseous components and particulate emissions. Hydrogen combustion and combustion of its mixture with a small ammonia fraction result in different concentrations of gaseous species. Combustion of pure hydrogen (Fig. 1b) produces low NO concentrations, ranging from about 30 ppm to over 300 ppm at higher λ values, associated with lean charge combustion. In contrast, a small ammonia share (5%) leads to more than a tenfold increase in NO_x emissions, resulting from the fuel-NO formation mechanism described by the Zeldovich model. Analysis of unburned hydrogen (Fig. 1b) indicates higher values under significantly leaner combustion conditions. In this case, the use of hydrogen or ammonia does not result in significant differences.

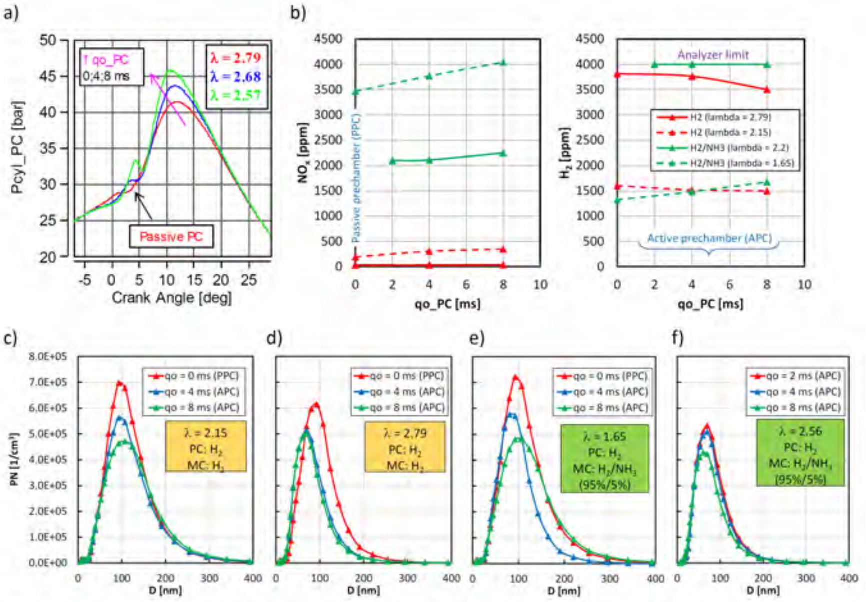

Fig. 1. Engine test results: a) indicator measurements (point: H_2; λ = 2.79); b) exhaust gas concentrations; and particle number distributions (n = 1400 rpm): c) λ = 2.15, H_2; b) λ = 2.79, H_2; c) λ = 1.65, H_2+NH_3; d) λ = 2.56, H_2+NH_3

Analysis of particle number distributions (Fig. 1c-f) indicates that combustion of different carbon-free fuels has a limited effect on particle number characteristics. Under very lean combustion conditions, particle number decreases from 7E+05 1/cm³ at a diameter of 100 nm to 6E+05 1/cm³. Similar trends were observed for combustion of the hydrogen–ammonia mixture. Each increase in pre-chamber fuel dose reduces the maximum particle number. An increase in excess air ratio shifts particle number distribution curves toward smaller particle diameters.

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Secondary Organic Aerosol Formation of Vehicle Emissions under Realistic Driving Conditions in a Road Tunnel

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Abstract: Traffic emissions constitute a significant source of secondary organic aerosols (SOA) in urban environments. However, distinguishing vehicular emissions to SOA formation under realistic driving conditions remains challenging due to complex ambient mixtures. Molecular-level characterization of both gas-phase precursors and SOA chemical composition is essential for better understanding traffic-related emissions and their impact on urban air pollution. In this study, three weeks of field measurements were conducted in the Fréjus Tunnel to characterize vehicular emissions under real-world conditions. An oxidation flow reactor (OFR) was deployed to simulate atmospheric aging of emissions across a wide range of OH exposures. By integrating VOCUS proton-transfer reaction time-of-flight mass spectrometry (VOCUS PTR-MS) and extractive electrospray ionization time-of-flight mass spectrometry (EESI-TOF), we determined the gas-phase precursors and particle-phase chemical composition of SOA from a diverse traffic fleet. Our results highlight the significant contribution of long-chain alkanes from vehicular emissions to SOA formation and reveal a higher abundance of moderately to highly oxygenated molecules formed through photochemical oxidation.

Key Words: Secondary Organic Aerosols, Vehicle Emissions, Oxidation Flow Reactor

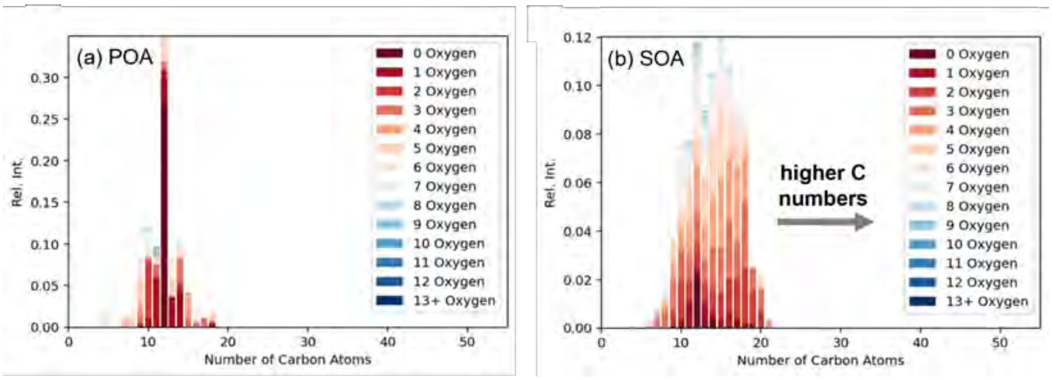

Figure 1. Comparison of the carbon number distribution of (a) primary organic aerosol and (b) secondary organic aerosols through photochemical oxidation, colored by oxygen atom number.

How Urea Dosing in SCR Systems Drives Secondary Particle Formation

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Urea injection in SCR systems can generate ultrafine, non-volatile particles (<23 nm) [1], which may become a dominant emission source in low-soot engines such as hydrogen combustion systems [2]. This study investigates the formation mechanisms of these urea-induced particles under controlled conditions. A heavy-duty exhaust aftertreatment system is used with three exhaust gas sources (diesel engine, hydrogen engine, hot gas burner). Urea dosing is varied under steady-state conditions, while PN10 and PN23 emissions are quantified at the tailpipe using an AVL APC 489. A clear linear correlation between urea dosing rate and PN emissions is observed. The exhaust gas composition and the catalysts variations show negligible impact, while exhaust gas temperature strongly influences particle formation, with a maximum around 400 °C. Experiments with particle-free exhaust (hydrogen engine, hot gas burner) confirm urea as the primary particle source, while results with diesel exhaust require correction due to background soot and ash. Consistent trends across all configurations indicate that particle formation is driven mainly by urea decomposition by-products rather than exhaust gas constituents. The use of a static mixer increases PN emissions, suggesting that enhanced atomization and accelerated urea decomposition promote particle formation. Further detailed analysis with a TiO_2-based hydrolysis catalyst show that improved conversion of urea to ammonia reduces intermediate species and significantly lowers PN10 emissions while maintaining NO_x conversion efficiency. The results indicate that intermediate species—particularly isocyanic acid (HNCO)—play a key role in forming solid ultrafine particles, whereas ammonia itself does not contribute to increased particle numbers. Particle formation in SCR systems is governed by urea dosing and the completeness of urea decomposition. Incomplete conversion leads to reactive intermediates that drive secondary particle formation, likely via gas-phase polymerization processes. Future work should focus on identifying the chemical composition of urea-induced particles. This study is funded by the Research Association for Combustion Engines (FVV1464).

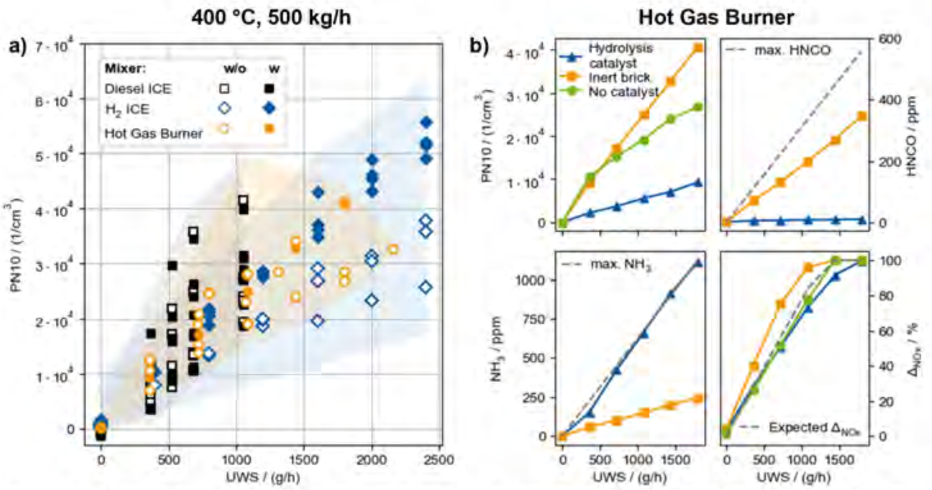

Figure 1: a) Urea-induced PN10 emissions at tailpipe for steady-state operating conditions, b) Reduction of secondary urea-induced particles by enhanced hydrolysis.

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Cost-benefit: Electrostatic precipitators for residential stoves

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Background: Residential heating with wood (and coal) in small stoves is a significant pollution source in many countries. The smoke contains same toxic particles and carcinogenic PAHs as tobacco smoke and increases the risk of cancer, blood clots, cardiovascular diseases, serious lung diseases, etc. Thereby contributing significantly to mortality and morbidity, i.e. imposing a very expensive health burden on society. However, the expensive health burden could make requirements for electrostatic precipitators for new residential stoves a positive investment for society. **Purpose:** The purpose of this study was to perform a cost-benefit screening of the following scenario: the ongoing revision of the EU Ecodesign regulation for stoves leads to an outcome where electrostatic precipitators (or similar technology) will be a mandatory requirement for new wood stoves. Furthermore, externalities due to air pollution (health costs only) and climate pollution have been calculated per Gigajoule (GJ) of house heating for new wood stoves (with/without precipitators) in comparison to heat pumps. **Methods**: Calculations were conducted for densely populated urban areas, smaller towns, and rural areas, as the latter typically have more intense use of biomass than the former, in Denmark and Slovakia, two EU countries that have same size but quite different per-capita average income to illustrate the consequences in both wealthier and less wealthy countries in the EU. Costs of precipitators in case of mass production were estimated to be 1,000 euro. Specific fuel use and health externalities for densely populated urban areas, smaller towns, and rural areas in Denmark and Slovakia were used. General air pollution health externalities in Denmark and global warming per GJ of heating for existing Ecodesign wood stoves (with/without precipitators) and heat pumps were calculated including four air pollutants: $PM_{2.5}$, NOx, NH_3, and SO_2, and four climate pollutants: CO_2, CH_4, N_2O, and BC. **Results:** Annual cost of electrostatic precipitators represents only 0.2-0.5% of the incomes in Denmark and Slovakia. As a result, making electrostatic precipitators mandatory for new wood stoves would not pose a general financial burden but some families might need financial support to install precipitators. The benefits to cost ratio of requiring electrostatic precipitators for residential stoves is 2.7-19.4 making it a beneficial investment for society if the revised Ecodesign regulation mandates the use of electrostatic precipitators for stoves. Even though the externalities are highest per kg $PM_{2.5}$ in densely populated urban areas, the benefits to cost ratios are highest in rural areas because of significantly higher fuel use per stove and because $PM_{2.5}$ spread far from the source causing exposure on a regional level. The general health costs of air pollution from a new wood stove meeting current Ecodesign regulations in Denmark are approximately 180 times higher per GJ of household heating than those from even a coal-powered electric heat pump. If electrostatic precipitators are made mandatory in the Ecodesign regulation, new wood stoves would still result in about 70 times higher health costs per GJ of heating compared to a coal-powered heat pump. Climate pollution from a wood stove complying with current Ecodesign regulations causes significantly more global warming per GJ of household heating than a heat pump powered by coal-based electricity. This remains true even when assuming that CO_2 emissions from wood stoves are entirely carbon neutral. Electrostatic precipitators reduce the BC emission from wood stoves, thereby substantially lowering their climate impact. **Acknowledgement:** This study was funded by the Clean Air Fund and the European Climate Foundation.

Field investigations of particle pollution from residential heating in Slovakia

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[1]Green Global Future, [2]Centre for Sustainable Alternatives

Background: Residential heating with wood and coal in small stoves and boilers is the dominating source of particle and PAH emissions in Slovakia and contributes significantly to the local pollution in small villages and towns. This increases the risk of cancer, blood clots, cardiovascular diseases, lung diseases, etc. Thus, contributing significantly to mortality and morbidity, placing a heavy and expensive health burden on society. Burning wood and coal in stoves can also pollute indoor air due to emissions inside the home causing high particle pollution during the cold seasons when people spend most of their time indoors and ventilation is limited. The health damage associated with indoor air pollution is usually not included when calculating the health burden of air pollution. **Purpose:** The purpose was to conduct field investigations in Slovakia, measuring particle number concentrations in Slovak nature with no local pollution sources, in village areas (e.g. parks) with no smell of wood/coal smoke, and while walking in residential areas heating with wood and coal. **Methods:** Particle number was measured with calibrated P-Traks from TSI in 31 Slovak villages in the winter 2020, 2023, 2024, and 2025. No other significant local pollution sources were active during measurements (pollution from passing diesel cars was noted and removed from result). **Results:** Background pollution in Slovak nature typically ranged from 500-1,000 particles per cm^3 depending on weather conditions, i.e. people in Slovakia would inhale what the WHO considers as a low pollution level if national pollution sources were eliminated. In village areas (e.g. parks) with no smell of wood/coal smoke were typically 2,000-6,000 particles per cm^3. However, during inversion periods in valleys, the concentration exceeds 10,000 particles per cm^3 in village areas with no smell. While walking on streets in residential village areas, particle concentrations (minute averages) could locally exceed 40,000 particles per cm^3 which WHO considers to be a high pollution level. Supplementary indoor measurements in a few homes (without other active pollution sources) revealed concentrations above 50,000 particles per cm^3. **Conclusion:** This field study confirms that local heating with wood and coal in villages in Slovakia generally contributes significantly to local pollution with increased particle number and that stoves can contribute to high indoor air pollution. **Acknowledgement:** This work is funded by the EU LIFE program: Project LIFE-IP SK AQ Improvement.

Chemical composition of tarballs and "charballs" formed by pyrolysis of wildfire-like organics

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Biomass burning (BB) in wildfires and residential settings involves the pyrolytic depolymerization of cellulose and lignin to form primary BB organic-aerosol particles (BBOA) via bubbling or condensation. BBOA typically contains brown carbon (BrC), a complex mixture that absorbs light more strongly at shorter wavelengths. While low-volatility BBOA is known to be darker and possess a higher mass-specific light absorption (MAC) than bulk BBOA, previous studies typically determined volatility–MAC relationships by heating BBOA to achieve partial evaporation. For highly thermolabile BBOA, this process also induces carbonization.

Here, we investigate this carbonization process systematically by rapidly pyrolyzing laboratory-generated BBOA (~1 s) at temperatures representative of wildfire plumes and residential stoves: 150–450 °C. We show that this BBOA, initially comprising ≈1–3 kDa molecules, carbonizes into macromolecular, insoluble "tarballs" at moderate temperatures (100–300 °C) and into "charballs" (black-coloured nano-char spheres) at temperatures >350 °C. Although insoluble, this intermediate dark-BrC material was detectable by an aerosol mass spectrometer (HR-AMS). The HR-AMS exhibited a four-fold reduction in sensitivity after 250 °C treatment, despite a sample OC/TC of 0.8. Thus, the tarballs represent an intermediate material between organic and black carbon.

Above 350 °C, HR-AMS signals were negligible; charball quantification required the SP-AMS 1064-nm laser. The SP-AMS mass spectrum indicated that no refractory organics remained. It comprised only oxygenated ions (CO^+, CO_2^+, H_2O^+), metals (Ca^+, K^+), and refractory black carbon (rBC) ions C_x^+. The rBC fragmentation pattern was indistinguishable from that of mature soot at all heat-treatment temperatures. The O/C ratio inferred from the SP-AMS mass spectrum showed excellent agreement with energy dispersive X-ray spectroscopy (EDS) measurements. Overall, these results provide mechanistic insights into the composition of nano-char aerosols, while identifying a measurement gap where moderately carbonized tarballs are significantly under-measured by both HR-AMS and SP-AMS. Failure to account for this gap may result in a substantial underestimation of the particulate mass and radiative forcing of BBOA smoke.

Reducing the uncertainty of condensation particle counter calibrations at low particle number concentrations by reducing electrical noise in the Faraday cup aerosol electrometer

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The latest version of the European Ambient Air Quality Directive [1] mandates the measurement of the number concentration and size distribution of ultrafine particles. The European standard EN 16976:2024 [2] sets out a method for the measurement of the particle number concentration of ambient air using condensation particle counters (CPCs). CPCs measure particles in the size range from 10 nm to a few micrometers. Measurements of particle number concentration are also required by vehicle legislation such as Periodic Technical Inspection legislation [3] and aerospace engines emissions legislation [4].

In 2026 NPL increased its ISO 17025 scope of CPC calibrations against a reference Faraday Cup Aerosol Electrometer (FCAE) in accordance with ISO 27891[5], reducing the lower end of the concentration range from 1000 cm^{-3} (1.5 fC cm^{-3}) to 100 cm^{-3} (0.15 fC cm^{-3}). At these ultra-low currents, the zero noise and zero offset of the reference Faraday cup electrometer start to become significant contributors to the overall uncertainty in the CPC calibration. Coupled with the difficulty to calibrate the reference FCAE at charge concentrations below 1.5 fC cm^{-3} this forms an important measurement challenge.

This work examines the process of driving down the measurement uncertainties at ultra-low currents. This was achieved by modifying the calibration procedures of both the CPC and primary FCAE. The primary FCAE calibration was modified to increase the measurement duration at the lowest currents to minimise the contribution of the electrical noise. The improvements in CPC calibrations, included physical adaptions such as vibration dampening, using fixed brick installations rather than standard laboratory benchtops and additional ambient background charge insulation external to the body of the FCAE. The sampling periods during the calibrations were adjusted to minimise the contribution of the fluctuations in the FCAE instrument noise with a focus on the crucial zero current measurments and a new approach was taken to dealing effectively with the FCAE zero offset, to minimise its contribution to the overall measurement uncertainty.

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[2] European Committee for Standardization, European standard EN 16976:2024 Ambient air - Determination of the particle number concentration of atmospheric aerosol, 2024
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[5] International Organization for Standardization, International standard ISO 27891:2015 Aerosol particle number concentration, 2015

Lowcost ambient UFP monitoring with diffusion chargers

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Over the past years, there has been increased interest in measuring ultrafine particles (UFP) in ambient air to complement existing particle mass metrics (PM10, PM2.5). The renewed interest stems from the new WHO recommendations to measure UFP, and the new EU air quality directive which mandates UFP measurements.

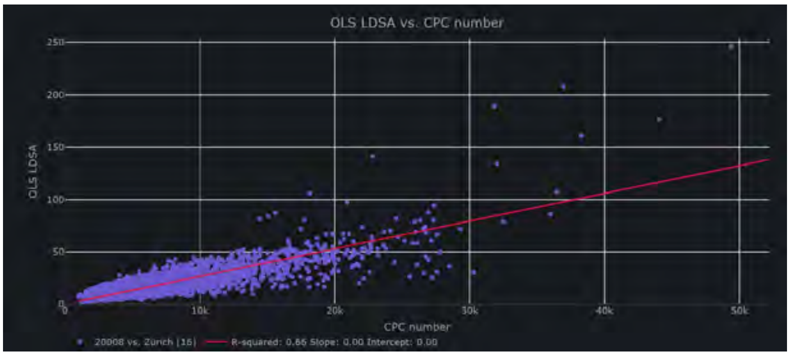
Due to the complexity and cost of traditional UFP measurements (with condensation particle counters (CPC) for particle number, and the mobility particle size spectrometer (MPSS) for particle size distributions), there will always be insufficient coverage of UFP metrics, in particular as it is well known that UFP concentrations vary more spatially than the traditional PM2.5/PM10 measurements.

To address the issue of low spatial coverage, we have developed a low-cost diffusion-charging based device that can be deployed anywhere, i.e. outside of traditional measurement stations with complex inlet systems and climate-controlled interiors, as long as power (~4 Watt) is provided. The sensor measures the charge transfer to the aerosol, which is roughly proportional to the lung-deposited surface area (LDSA), a metric which has the potential to be interesting for health effects. The full instrument consists of the LDSA sensor (OLS) coupled with a data transmission/control unit enclosed in a weather-proof box. Measurement data and instrument status information is transmitted to a cloud backend, from where the data can always be visualized online in any browser.

The new instruments have been deployed on a larger scale in early 2025 within the EU project "net4cities" (33 devices in 11 partner cities in Europe), as well as another 9 instruments measuring in and around Zürich. These ~40 instruments have been running nearly one year in 24/7 operation with no onsite intervention necessary so far, only minor over-the-air-updates of the software were performed until now. The data availability is roughly 99%. Some of the instruments are co-located with traditional devices; and in two locations, multiple instruments have been deployed to the same location, which allows to assess how well the instruments agree over longer times.

The measured LDSA values correlate reasonably well with CPC number concentration measurements, e.g. for the location Zürich-Kaserne, we observe an R2 of 0.68 for hourly values of the fourth quarter of 2025 (see figure below). This shows the similarity of LDSA and particle number measurements, and means LDSA could well serve as UFP complement to existing PM measurements.

In conclusion, the observed high reliability, high data quality, low maintenance combined with ease of deployment and operation and low cost of this new instrument appear to allow UFP measurements on far larger scale than was possible with traditional instruments.



Uncertainty of the dilution factor of diluters with internal mixing gas preparation

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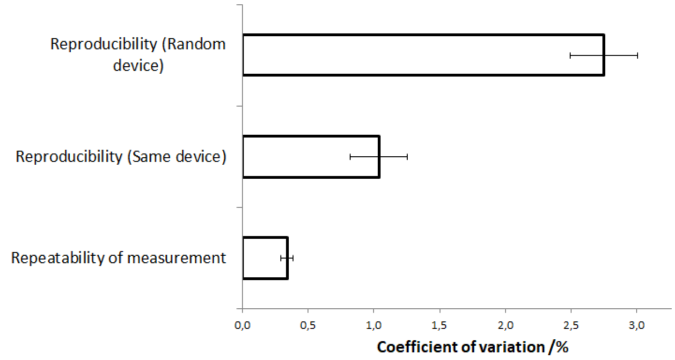
Dilution systems are widely used to adjust the concentration of aerosols, either during the generation or quantification of aerosols. Dilution systems with internal mixing gas preparation are often used for this purpose [1, 2]. They are based on the passive passage of a defined total flow rate of the aerosol to be diluted. This flow is divided into two partial flows. A small partial volume flow flows through a capillary, whereby its particle concentration remains constant, if losses within the capillary can be neglected. The majority of the total flow passes through a bypass consisting of a valve and an absolute filter for particle separation and then mixes again with the capillary flow. The valve adjusts the ratio of the two volume flows and thus the dilution ratio of the system.

The dilution rate is not a measurand as defined by GUM [3], because it is not measured during the application. Nevertheless, the concept of quantifying its uncertainty can be applied. To quantify the uncertainty of the dilution rate, the dilution rate of a diluter (DIL 554, Topas GmbH) was measured independently from the calibration process, according to type A evaluation of standard uncertainty of GUM.

The dilution rate was measured by two CPCs upstream and downstream the diluter employing a DMA-classified DEHS test aerosol. With a sample duration of 115 s the standard deviation of the downstream sample is 3.9 %, which is dominated by the counting process of the CPC. The standard deviation of the mean is estimated according to GUM to 0.36 %, which is confirmed by the measurement of the repeatability (repeated measurement of dilution factor without any user intervention) in figure 1. This indicates that only random errors dominate the measurement uncertainty. The measurement of the dilution rate was repeated 30 times with the same device and 90 times with 10 randomly selected devices to quantify the reproducibility (figure 1).



The contribution discusses the applied method to quantify the uncertainty of the dilution rate and aims on developing a common method to evaluate the uncertainty of dilution systems to enable the comparison of results.

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Testing and Calibration of bcMeter, an Open-Source, Low-Cost Black Carbon Monitor

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Black carbon (BC) is a major short-lived climate forcer and air pollutant, yet significant gaps remain in global data collection, partly due to the high cost of reference-grade instruments. The open-source bcMeter offers a low-cost alternative for monitoring BC; however its performance has not been sufficiently evaluated.

This paper investigates the bcMeter's accuracy in measuring BC, the factors influencing its performance, and its suitability for deployment in resource-limited environments. A six-test co-location campaign involving three bcMeter units (BCM A–C) and an AE33 reference aethalometer was conducted at two Swiss sites (Dübendorf and Zürich) over a total duration of 30 days. The study assessed performance at a ten-minute temporal resolution, higher than previously reported, and examined the effects of filter loading, tube material, and temperature fluctuations. Data were pretreated, and two post-processing approaches were applied: centered moving average (CMA) smoothing and multiple linear regression (MLR) prediction incorporating environmental predictors.

Results show that, despite inherent noise, the bcMeter reliably captures temporal BC trends under suitable conditions or with appropriate data treatment. When comparing the collocation data of AE33 and bcMeter, R^2 values were 0.59–0.74 for pretreated data, improving to 0.65–0.78 with MLR and 0.74–0.85 with CMA calibration. Filter loading caused a reduction in R^2 of more than 30 percent and led to systematic underestimation, while instrument temperature fluctuations were identified as the main driver of large residual spikes. Polyurethane tubing outperformed conductive PVC in short-term stability. CMA reduced noise at the expense of fine temporal detail, whereas MLR preserved more detail but was more sensitive to large deviations from AE33 readings.

With a hardware cost below 300 CHF, the bcMeter demonstrates strong potential for low-cost BC monitoring. However, careful evaluation of the intended application and available infrastructure is essential to ensure proper calibration and reliable operation, especially in resource-constrained settings. Future efforts should focus on automated filter tape advancement and methods to compensate for environmental effects, thereby supporting robust, scalable field deployment and enhancing performance.

Performance characterisation of a continuously variable aerosol diluter

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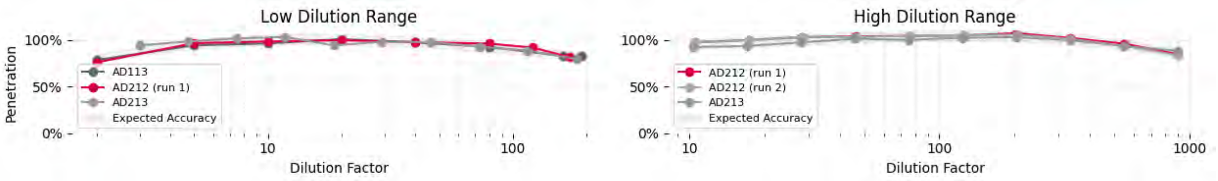
Dilution is a ubiquitous requirement in aerosol research and instrument testing, yet many diluters offer a very limited range, fixed steps or couple dilution to fixed flow conditions. The Cambustion AD60 (2025) is a variable standalone rotating disc aerosol diluter. The AD60 was developed to address various requirements; to provide stable, repeatable and reproducible dilution factors from approximately 2 to 900, while offering users independent control of inlet and outlet flows (1-3 slpm and 1-15 slpm, respectively). Aerosol is diluted by transferring a precisely metered volume of particle-laden gas from disc pockets into a bulk flow of HEPA filtered particle-free gas. This approach enables a wide range of dilution factors in a compact device and minimises aerosol losses and changes to particle properties.



Particle loss performance was characterised using a sodium chloride challenge aerosol generated by a Collison nebuliser. Upstream and downstream concentrations were measured by automated switching between bypass and diluted sampling paths. Both flow paths were matched in length and flow to measure the true penetration of the AD60; differences between the bypass and diluted paths are primarily attributable to the device under test. An automated test procedure stepped through the available dilution range, with bypass reference points to establish and correct for any challenge aerosol concentration drift. Penetration was calculated as the ratio of measured concentration to the expected concentration (bypass concentration divided by the nominal dilution factor). Particle generation (“background” concentration) was assessed by sampling the outlet with a HEPA fitted to the inlet.

The AD60 delivered stable dilution with good reproducibility and predictable penetration behaviour across operating conditions. Background particle generation remained below 1 cm^{-3} over the full disc-speed range. The penetration curves shown above, exhibit a maximum near the logarithmic midpoint of the dilution range, approaching 100%, and decreasing towards the edges of the operating map to around 80%. Thus, for any selected dilution factor there is an optimal outlet flow setting which can maximise particle penetration. Changing outlet flow (and therefore the achievable dilution range) preserved the characteristic shape of the penetration curves, providing a practical tuning parameter for a given experimental requirement.

Uncertainty propagation indicated an accuracy uncertainty of 5.31%, dominated by disc-pocket dimensional tolerance (5.17%), while within-unit repeatability was 1.25%, consistent with the measured repeatability, shown in the figure. For reproducibility between units, disc dimensional variation manifests primarily as a vertical offset between penetration curves, suggesting that additional unit calibration and adjustment can improve absolute accuracy if required. Overall, these results support the AD60’s suitability for high-concentration measurements, instrument linearity testing, and filter penetration studies where reliable, repeatable and adjustable dilution is required.

Towards Stand-Alone Monitoring of Carbonaceous Aerosol: FATCAT Measurements and Thermogram-Based Source Interpretation

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Carbonaceous aerosol is a dominant component of particulate matter with significant implications for climate and human health, yet its routine measurement at the compositional detail required for source apportionment remains elusive. Conventional metrics (equivalent black carbon (eBC) from optical measurements, or organic carbon (OC) and elemental carbon (EC) from thermal-optical analysis) rely on operationally defined fractions that do not map cleanly onto chemical properties, limiting their utility for distinguishing source contributions and ageing processes in ambient air.

The Fast Thermal Carbon Totalizator (FATCAT) addresses this gap by combining autonomous TC quantification with a novel measurement feature: fast thermograms [1]. In FATCAT, aerosol particles are collected on a robust sintered metallic filter, which is then flash-heated to ~800 °C in less than one minute. This generates reproducible CO_2 release profiles (thermograms) that reflect the volatility and refractoriness of the carbonaceous sample without imposing an artificial defined split.

Laboratory experiments with well-defined aerosol types, performed within the EURAMET 22NRM02 STANBC project [2], demonstrate the interpretive power of thermograms. Fresh soot from a propane flame generates a late, refractory-dominated signal, while secondary organic aerosol (SOA) coatings produce an additional early feature proportional to coating thickness, leaving the soot core signature intact. Wood-burning emissions from test-bench experiments yield intermediate features consistent with mixed OC/EC composition. Crucially, thermogram shape is reproducible and load-independent, enabling direct comparison across samples and measurement sites.

At the Jungfraujoch Global GAW station (3580 m a.s.l.), FATCAT operated autonomously over multi-month campaigns as part of the GAW-CH Plus research projects (2018–2021). The resulting time series of TC thermograms allows episodic pollution events to be characterised beyond bulk concentration: local fossil-fuel influence is fingerprinted by a refractory-dominated thermogram consistent with fresh soot, while aged biomass-burning plumes (including cases attributed to long-range transport from North American wildfires) exhibit an enhanced early volatile fraction consistent with secondary organic matter. Interpretation is supported by comparison with the synthetic aerosol from the STANBC project.

These results demonstrate that FATCAT thermograms provide a new autonomous technique to monitor carbonaceous aerosol, its composition, source attribution, and atmospheric ageing using a single device.

The 22NRM02 STANBC Metrology Partnership project has received funding from the European Partnership on Metrology, co-financed by the European Union Horizon Europe Research and Innovation Programme and from the Participating States.

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A portable optoacoustic BC sensor for source emission monitoring

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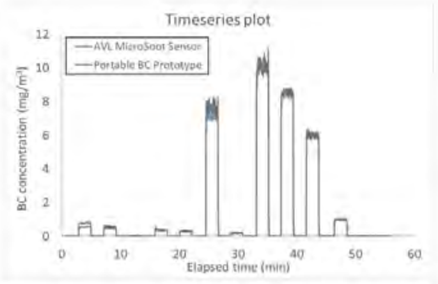
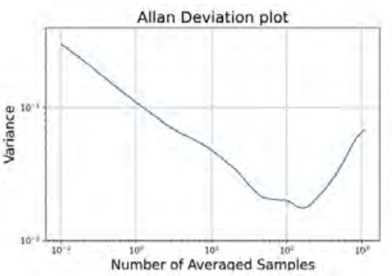
Black Carbon (BC) is a byproduct of combustion of carbon-containing fuels, that is defined partly by its strong light absorption properties [1]. It contributes significantly to climate change especially in snow-covered areas such as the Arctic where it leads to accelerated snow melting [2]. BC also has adverse effects on human health as it correlates with cardiovascular mortality and morbidity [3]. Absorption based techniques that can quantify BC are currently used for accurate source emission monitoring. Optoacoustics (aka Photoacoustics), is one such technique.

We have previously developed a low-cost optoacoustic sensor [4]. A portable, version of this sensor was developed, able to perform source emission monitoring. Extensive experiments are performed with BC particles generated under controlled laboratory conditions with an aerosol particle generator (AVL APG), to evaluate the sensor. The results show that our portable sensor has equivalent performance to a commercial lab-grade instrument, with an R2 equal to 0.99 and a limit of detection equal to 5 ug/m^3 for 1s averaging. In terms of exposure, the sensor was operated for tenths of hours in high concentrations in the range 2-15 mg/m^3, without the need for cleaning. Such sensitivity and durability, coupled with its small size and low-cost, make it a promising solution for BC source monitoring, even for harsh exhaust applications.





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Ultra-Simple, Cost-Effective, Single-Precursor Production of Co_3O_4 Nanoparticles via Thermal Decomposition: Characterization and Scalability-Oriented Techno-Economic Analysis

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Cobalt oxide (Co_3O_4) nanoparticles are widely used in catalysis, sensing, energy storage, and environmental applications, but many reported synthesis routes remain multistep, solvent-intensive, and less suitable for scale-up. In this study, an ultra-simple one-step thermal decomposition method was developed to synthesize Co_3O_4 nanoparticles directly from cobalt(II) nitrate hexahydrate at 420°C without solvents, surfactants, or additional wet-chemical processing.The synthesized product was characterized by X-ray diffraction, FESEM, and TEM. XRD confirmed the formation of crystalline cubic spinel Co_3O_4, while FESEM and TEM revealed a predominantly nanorod-like morphology with average dimensions of approximately 16 nm in diameter and 36 nm in length, confirming successful formation of phase-pure nanostructured material through this simplified route. A preliminary techno-economic analysis further demonstrated promising batch-scale feasibility for the proposed process, including integration of NO_2 scrubbing during scale-up. Sensitivity analysis showed that project profitability is more strongly influenced by sales performance than by moderate raw material price fluctuations. Overall, this study presents a simple, reproducible, and potentially scalable strategy for Co_3O_4 nanoparticle production with encouraging industrial relevance.

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

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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.

The project has received funding from PTB's TransMet (Transfer of Metrological Technology) programme, with the objective of fostering the research capabilities and competitive edge of small and medium-sized enterprises (SMEs) in Germany.

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

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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.