Session 9: Indoor particles and occupational exposure, Talk

Airborne pathogen detection via MASC-On - Magnetic Antibody Sorting Coupled with flow Cytometry Online

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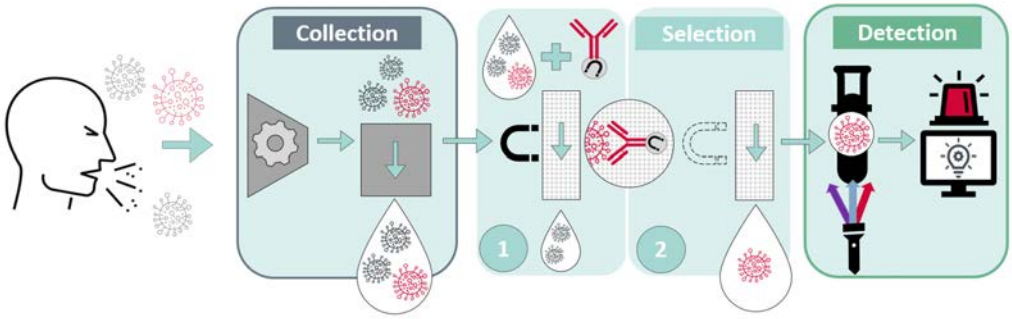

In light of the COVID-19 pandemic, airborne bioaerosol like bacteria and viruses are a major concern for human health. Therefore, monitoring of the concentrations of these bioaerosols plays a vital role in understanding disease transmission. Rapid, automated, quantitative and specific bioaerosol monitoring would allow for continuous assessment of airborne virus and bacteria at hospitals and similar locations.

In this proof-of-concept study, we develop and characterise a continuous pathogenic bioaerosol sampler and detector. The set-up consists of three main parts. In a first step (Collection phase), the bioaerosol is sampled continuously via a particle into liquid sampler. This bioaerosol liquid flow is mixed with an immunoassay (Selection phase) and then quantified in a flow cytometer (Detection phase).

We have already successfully connected all three phases into one continuous, automated, and autonomous prototype for pathogenic bioaerosol monitoring. With a time resolution of 60 minutes (of which 15 are spent on sample acquisition) our instrument collects 99.5% of nebulized E. coli bacteria continuously. Flow cytometry results were confirmed with agar plate analyses. Plating can only account for colony forming units, while flow cytometry can count all labelled cells.

While other instruments for automated pathogen detection exist, these techniques lack either specificity, quantification, automation or time-resolution. This novel mix of methods attempts to combine all factors mentioned. Our next step is to optimize further and apply this method to airborne virus.

Session 9: Indoor particles and occupational exposure, Talk

Physiologically Realistic Simulation of DEHP Penetration in the Human Airways

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Introduction: Di(2-ethylhexyl) phthalate (DEHP) is one of the most prevalent indoor phthalates, primarily due to its widespread use as a plasticizer in industrial and consumer products. During inhalation, airborne particles can act as carriers, transporting DEHP into the respiratory tract and facilitating its deposition within the airway lining fluid. This study presents a three-dimensional computational framework to investigate the penetration of nano-scaled DEHP, following its dissolution from particulate matter, into the airway surface liquid (ASL) of the human airways under physiologically realistic conditions, incorporating experimentally derived ciliary kinematics and mucus rheology. **Methods:** A hybrid immersed boundary–finite difference projection method is employed to discretize and solve the time-dependent governing equations for fluid flow, together with the convection–diffusion equation governing mass transfer within the tracheal ASL [1], accounting for the dissolution of particulate-bound DEHP into the ASL (Figure 1A). The immersed boundary framework enables accurate representation of cilia-driven fluid–structure interactions as well as DEHP–cilia interactions. Physiologically realistic ciliary properties are obtained from primary nasal epithelial cells derived from a healthy donor and cultured at the air-liquid-interface. Ciliary beat patterns are extracted from high-resolution microscopy images and incorporated into the computational model [2](Figure 1B). The mucus layer is modelled as a nonlinear viscoelastic fluid using a five-mode Giesekus constitutive model. Differential dynamic microscopy [3] is applied to quantify the frequency-dependent microrheological properties of mucus produced by epithelial cell cultures, providing experimentally derived inputs for the mucus rheology (Figure 1C and D). **Results:**The numerical simulations yield time-resolved, three-dimensional concentration fields of DEHP within the human ASL. This study presents, for the first time, a physiologically realistic numerical framework that simultaneously incorporates experimentally measured ciliary beat patterns obtained from high-resolution microscopy and mucus viscoelastic properties derived from differential dynamic microscopy. The results provide detailed insight into the spatiotemporal distribution of DEHP in healthy airways, accounting for the coupled effects of mucociliary clearance and particle–cilia interactions.

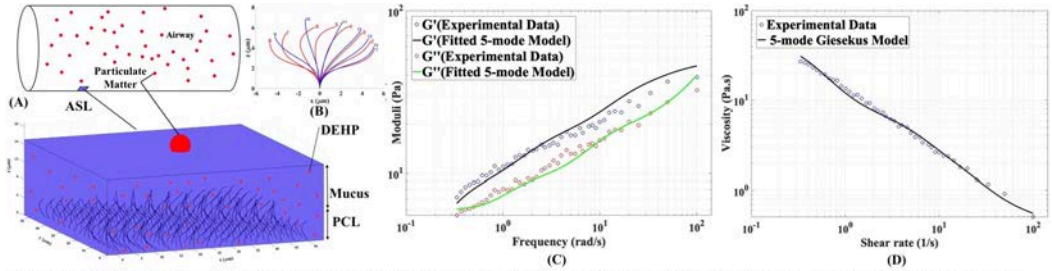

Figure 1. (A) Schematic of particulate matter transport in the airway, particle dissolution into DEHP, and subsequent penetration into the ASL. (B) Computer-generated ciliary configurations at 14 time steps; blue and red indicate effective and recovery strokes, respectively. (C) Experimental measurements and 5-mode model fits of the storage (G′) and loss (G″) moduli of mucus as functions of frequency. (D) Mucus viscosity as a function of shear rate from experimental data (symbols) and the 5-mode Giesekus model (solid line).

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Session 9: Indoor particles and occupational exposure, Talk

Lithium-ion battery thermal runaway particle emissions

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In recent years, the use of lithium-ion (Li-ion) batteries has seen significant growth, driven by their widespread application in electric vehicles and the broader energy transition. However, this increased use has brought to the forefront safety concerns, particularly regarding their susceptibility to thermal runaway. Thermal runaway is a violent chain reaction of exothermic chemical reactions resulting in an uncontrollable increase in system temperature, which can lead to a fire or explosion. Battery fires are known to pose significant environmental risks as they release aerosols and various toxic chemicals that can also adversely affect human health. Moreover, the methods used to extinguish these fires can alter the composition and nature of the emissions, further complicating the risks. For this study, Li-ion battery cells were triggered into thermal runaway via overcharging them. The battery cells were placed in a container and temperature and pressure were monitored throughout the experiment. The entire experiment was also monitored with cameras. Two experiments were performed where the battery fire was extinguished with water and with a chemical surfactant. Emission measurements were made for all experimental conditions, including fine particles collected onto filter media and real-time particle number and particle size distributions using a Dekati high-resolution ELPI+. PM chemical composition included the analysis of metals and trace elements with inductively coupled plasma mass spectrometry (ICP-MS), inorganic ions (lithium, ammonium, sodium, magnesium, potassium, calcium, fluoride, chloride, nitrate, sulfate, and phosphate) by ion chromatography, and polycyclic aromatic hydrocarbons (PAHs) by gas chromatography. Near-real-time metals were measured with a toxic metal aerosol analyzer (TARTA). The morphology and elemental composition of battery fire aerosols were analyzed by scanning electron microscopy (SEM) and energy-dispersive x-ray spectroscopy (EDS). The toxicological properties of PM were also measured by quantifying the oxidative stress, mutagenicity, and inflammatory markers.

Session 9: Indoor particles and occupational exposure, Talk

Occupational diesel exhaust exposure assessment using miniaturized aerosol instruments – intercomparison of aerosol instruments in different workplace environments

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Occupational exposure to diesel exhaust is regulated by the European Union Directive 2004/37/EC due to its carcinogenic effects. Diesel exhaust exposure of underground mine workers has been reported in many recent studies, but it is not well quantified in other sectors. New miniaturized instruments, such as micro-aethalometers and ultrafine particle counters, are potentially useful for the assessment of occupational exposure to particles. In this study, occupational exposure of bus drivers, bus depot mechanics, street maintenance workers, construction workers and inspection station workers was measured. Diesel exhaust exposure of the workers was measured as elemental carbon (EC) according to NIOSH5040 method and as equivalent black carbon (eBC) using portable micro-aethalometers (MA200, Aethlabs), and the lung deposited surface area (LDSA) was measured using a nanoparticle detector (Partector 2 Pro, Naneos). Background air quality in workplace environments was measured, including measurements of eBC (aethalometers AE33 and AE36s, Magee Scientific) and LDSA (NSAM, TSI and ELPI, Dekati). In addition, an intercomparison of the instruments was conducted in a laboratory setting. The test aerosol was produced with a Combustion Aerosol Standard (CAST) soot generator (Matter Engineering AG) using propane as fuel. Data from the miniaturized instruments was compared to EC results, data from other above-mentioned instruments as well as a scanning mobility particle sizer (SMPS, TSI) that was used as a reference instrument for particle size, mass and number concentration. Diesel exhaust exposure was below the occupational exposure limits in all workplaces and was clearly lower than the exposure levels in underground mines measured by the same authors [1]. High momentary concentrations were observed particularly during bus maintenance works at the bus depot. LDSA and eBC measured in the ambient air of workplace environments correlated well, whereas the correlation in personal exposure measurements was less clear. Ångström exponent (AAE) values for most workers were below 1 which indicates that the primary source of the carbonaceous aerosol was vehicular exhaust. A few construction workers, street maintenance workers and mechanics had an AAE value 1.2 or higher, which might imply there are black carbon sources besides traffic or a higher coating of diesel soot particles by organic matter [2]. The eBC results obtained with microaethalometers and aethalometers agreed well, whereas the comparability of Partector to SMPS in terms of particle size, mass and number concentration and to ELPI in terms of LDSA wasn't as good. At low concentrations the EC/eBC correlation was weak, which should be considered when using aethalometers for assessing exposure to diesel soot. Overall, the diesel exhaust exposure levels of the workers were below the regulation limit, but high momentary exposure peaks related to specific work actitivities were identified. The correlation between LDSA and eBC indicates that black carbon plays an important role in exposure to fine particles in the studied workplaces. This work was supported by the Finnish Work Environment Fund (grant 240104), Mestar Kuopio Oy, Koiviston Auto Kuopio Oy and A-Katsastus Oy.

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[2] Virkkula, *Atmospheric Measurement Techniques*, **2021**, 14, 3707–3719.

The MARKOPOLO Indoor/Outdoor project: Real-time assessment of residential ultrafine particle exposure indoors and outdoors

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Ultrafine particles (UFP, <100 nm) are of concern due to their ability to penetrate deep into the respiratory tract and translocate to other organs, leading to potential adverse health effects. As individuals spend much of their time indoors, accurate assessment of indoor UFP exposure is essential.

The MARKOPOLO ("Markers of Pollution") indoor/outdoor project investigates how outdoor concentrations, residential building characteristics and everyday occupant behaviour influence indoor UFP number concentrations (PNC) using real-time measurements. The study aims to include 60 Swiss households, each monitored during two one-week periods during the warm and cold seasons, capturing seasonal differences in behaviour, ventilation, and heating conditions. In each household, air quality sensors are installed both indoors and outdoors simultaneously, measuring PNC at a temporal resolution of 1 second, and $PM_{2.5}$, CO_2, temperature and relative humidity at 5-minute resolution. This captures short-term concentration peaks resulting from indoor behaviours and activities that would be obscured in daily or multi-hour averages.

To link concentration dynamics with occupant activities, participating households complete a time-activity diary with 10-minute resolution, documenting activities known to influence indoor particle levels, such as cooking, candle burning, fireplace use, and window opening. So far, 35 households could be recruited in four categories: 11 residences with indoor fireplaces, 6 Minergie-certified buildings, 9 households located along heavily trafficked roads, and 13 control households, with 4 households belonging to two categories.

Data collection is still ongoing. Initial observations show pronounced short-term increases in indoor UFP concentrations associated with combustion-related activities, particularly cooking and candle burning. Outdoor PNC was significantly associated with indoor PNC, but indoor combustion-related activities, particularly woodburning, cooking and candle burning are more strongly associated with short-term increases in indoor PNC.

The study highlights the value of real-time measurements for accurately characterizing residential UFP exposure and the effects of building properties and occupant behaviour.

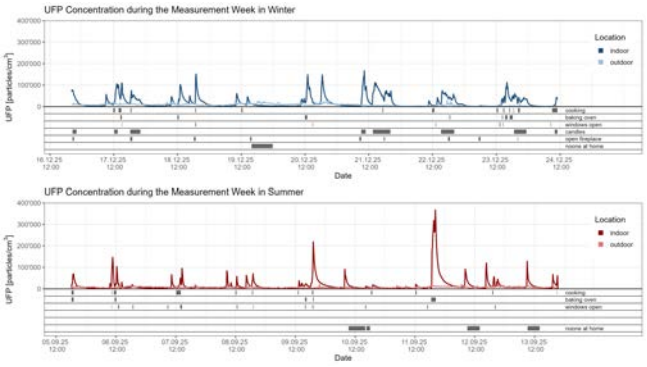
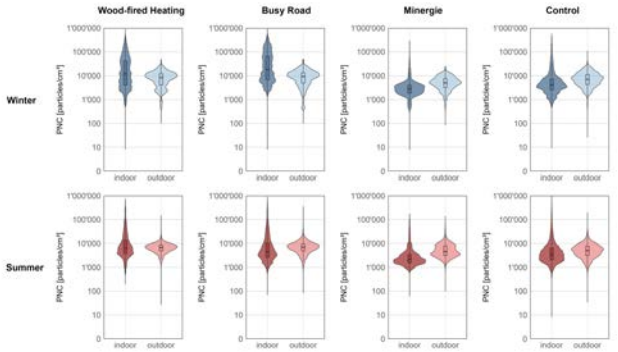


Figure 1: Particle number concentrations over time during summer and winter, with household activities logged below.

Figure 2: Distribution of measured indoor and outdoor ultrafine particle number concentrations (PNC) across residential categories during the winter and summer campaign.



Session 9: Indoor particles and occupational exposure, Talk

Underground Rail Air Quality: Determination of UFP and BC Concentrations in a Train Station and its Adjacent Tunnel

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Introduction: Recognized as a more environmentally friendly alternative to cars and airplanes, rail transport plays a crucial role in connecting Germany with other European countries, serving daily millions of passengers over a railway system of over 33,470 km [1]. Nonetheless, the growing evidence that train emissions also contribute to air pollution [2, 3, 4] has not yet been matched by extensive research, leaving this sector relatively unexplored compared to road transport. This work seeks to contribute to a deeper understanding of rail-related emissions, specifically focusing on UFP and BC.

Methodology: From January to March 2024, air quality measurements were carried out at four strategic locations at the Berlin Airport Train Station: the platform, tunnel, tunnel portal, and an outdoor brackground site (shown in Figure 1). At each measurement station, the concentrations of PM10 and PM2.5 were determined gravimetrically via sequential samplers, the filters were later analyzed for Black Carbon and Brown Carbon (BC and BrC) using an non-destructive Optical Transmissometer. These time-averaged data were complemented by continuous monitoring of coarse/fine particles (light-scattering), UFP (diffusion charger), and BC (mini-aethalometers). Finally, meteorological data such as temperature, humidity, wind speed and direction was collected to assess how natural airflow and vehicle-induced turbulence governed pollutant dispersion within the tunnel.

Results: As shown in Table 1, BC levels near the railway tracks significantly exceeded ambient background concentrations. BrC levels, however, remained relatively stable across sites, confirming the absence of internal BrC sources and suggesting that indoor concentrations are primarily driven by external air exchange. The study period was further marked by two railway strikes and one airport strike, which allowed us to differentiate traffic-related emissions from regional background signals and filter out potential interference from neighboring air traffic. ***Evaluation of the continuous UFP and BC time-series is currently being finalized.***

Conclusions and Outlook: This study confirms that track-side BC levels significantly exceed background concentrations, driven by traffic and the piston effect. BrC stability suggests external infiltration rather than internal sources. Ongoing high-resolution analysis of UFP and BC time-series will further clarify these emission patterns and their impact on air quality.

Figure 1. Location of Measurement stations

Table 1. Average BC Concentration

Station	BC (IR)* [µg/m³]	BrC (UV)** [µg/m³]
Tunnel portal	1.17	1.22
Tunnel	1.25	1.46
Platform 1-2	1.62	1.34
Willi-Brandt Platz (Background)	0.94	1.22

* BC (IR) = Black Carbon measured at 880 nm (Infrared)
** BrC (UV) = Brown Carbon measured at 370 nm (Ultraviolet)

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