Analysis of Morphological and Chemical Properties of Tyre and Brake Wear Particles Using Real-Time Measurement Techniques

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This study focuses on the real-time analysis of tyre and brake wear particles (non-exhaust emissions) by utilising advanced techniques. The research aims to better understand the dynamics of these emissions under controlled conditions. The primary goal is to explore the morphological and chemical properties of non-exhaust emissions using real-time data acquisition methods for a better understanding of the factors that lead to tyre abrasion.

The study aims to evaluate the feasibility of measuring non-exhaust emissions with advanced instrumentation and to compare the accuracy of direct and indirect sampling methods to support further regulatory frameworks with robust emission data.

A chassis dyno test bench with testing vehicle, which is equipped with a tyre particle sampling system (DLR tyre testing system™), was used. Direct sampling involved immediate particle collection from emission sources, while indirect sampling accumulated particles before analysis. Digital holography, UV-induced fluorescence spectroscopy techniques were employed for morphological and chemical analysis using a SwisensPoleno Jupiter [1] which can differentiate several microplastics classes under laboratory conditions [2].

The analysis revealed that indirect sampling captured larger particles, whereas direct sampling showed limitations for particles >20 μm. with strong correlations between mechanical stress and emission characteristics. Comparative analysis highlighted significant differences in size distribution between sampling methods.

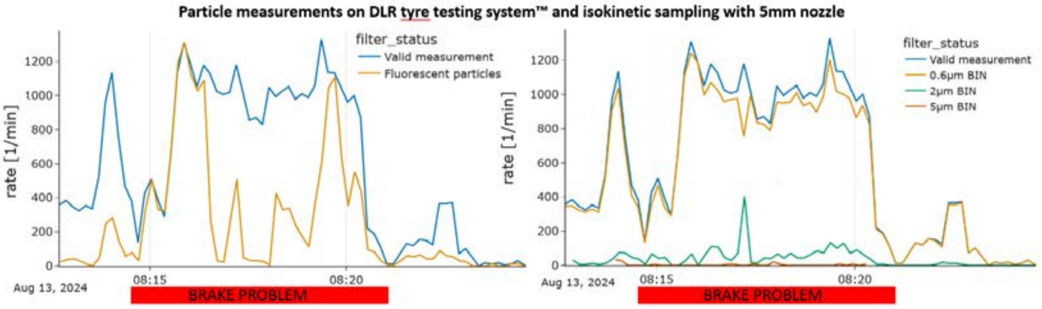

Figure 1: left: rate of valid- and fluorescent particles measured. Right: Particles binned by size measurement based on light scattering. Left and right: Brake problem phase indicated by the red bar.

Sampling of larger particles necessitating optimized sampling setups. These findings emphasize the need for standardised emission measurement protocols and support upcoming regulations.

This research demonstrates the effectiveness of SwisensPoleno Jupiter, in characterising non-exhaust emissions, providing a foundation for future environmental policies and sustainable automotive technologies.

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[2] Beres, Nicholas D., Julia Burkart, Elias Graf, Yanick Zeder, Lea Ann Dailey, and Bernadett Weinzierl, *Atmospheric Measurement Techniques*, 2024, 17 (23): 6945–64

Advancing Tire and Road Wear Particles (TRWP) Measurements: Balancing Laboratory Conditions and Real-World Relevance

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Airborne non-exhaust emissions (NEE) from road traffic originate from multiple sources, including brakes, dry clutches, tires, and roads. A significant proportion of these pollutants is believed to consist of airborne tire and road wear particles (TRWP). Studies on airborne TRWP typically involve particle collection in field conditions or controlled laboratory setups. Literature reviews report that airborne TRWP may contribute 5–30% of total road transport PM_{10} emissions, depending on a wide range of conditions [1]. The need for reliable TWP measurement methods has been highlighted in the literature to improve overall understanding [2]. This knowledge is crucial to assess whether airborne TRWP in urban environments pose a public health concern. The contact between the tire and road can be divided into a rolling and a sliding (tire slip) part. Most primary TRWP are generated from the sliding interaction between road surfaces and tires. Existing experimental approaches sometimes overestimate slip speed, resulting in excessively high contact temperatures. Consequently, the airborne TRWP generated and analysed under such conditions may not accurately represent those from real-world road use, especially nanosized particles. Furthermore, some experimental methods fail to include both contact surfaces (tire and road), which is essential to simulate the actual tribological mechanisms occurring during real driving.

This study identifies representative load and slip conditions using a scaled experimental approach. The method allows testing under different nominal contact pressures and slip speeds. Load and slip speed conditions are iteratively adjusted based on visual comparisons of tire wear scars to those observed on real, used car tires. A pin-on-disc tribometer, designed specifically for NEE studies, was employed to investigate friction, wear, and airborne TRWP. Test specimens were prepared from a used commercial tire (pin) and an asphalt road disc (SMA11 with pen. Bitumen 70/100). The tribometer was enclosed within a sealed box. During testing, compressed particle-free air (35 L/min) was directed at the contact zone to maintain clean air within the box and simulate airflow equivalent to 100 km/h, cheering wear particles to become airborne. A TSI CPC and a Grimm MiniWRAS were used to measure particle number concentrations inside the box. Nominal contact pressure was varied between 0.64 and 2.56 bar, with sliding speeds ranging from 0.08 to 0.16 m/s (28.8 to 56.7 km/h car speed assuming a tire slip of 1%). Test durations ranged from 30 to 120 minutes, corresponding to a total sliding distance of 576 meters (57.6 km of driving assuming a tire slip of 1%).

The results indicate that sliding speed and normal load strongly influence friction and wear behaviour, and resulting TRWP generation. Under moderate contact conditions, almost no concentration ($< 2\ \mathrm{cm}^{-3}$ for both instruments) of airborne TRWP were measured inside the box. These conditions produced smooth surfaces, a stable coefficient of friction, and reasonable coefficient of wear. Airborne TRWP were observed under severe or catastrophic contact conditions, where friction and wear mechanisms (and contact temperatures) drastically changed, resulting in significant detachment of tire material. However, such worn contact surfaces are not representative of those found on road-used car tires. This study therefore suggests prioritizing representative test conditions in future experimental studies, as they better replicate real-world driving conditions.

1. Giechaskiel B, et al. *Contribution of Road Vehicle Tyre Wear to Microplastics and Ambient Air Pollution*. Sustainability, 16, 2024
2. Mennekes D, Nowack B, *Tire wear particle emissions: Measurement data where are you?* Sci. Total Environ., 830, 2022

Enhancing the testing methodology for measuring tyre abrasion

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Road transport is one of the major contributors to environmental pollution. The exhaust emissions have been regulated for years, and with the current trend, it is expected that by 2050, non-exhaust emissions (NEE) will constitute up to 90 % of all particles emitted by road transport [1]. The Euro 7 regulation, which has recently been introduced, is the first legislation where non-exhaust emissions are regulated. In this context, more research is needed regarding the standardisation of the testing methodologies for measuring tyre abrasion.

At DLR, NEE have been a focus for the past years. For instance, a zero-emission vehicle (ZEDU-1) was designed aiming to promote the transition towards clean mobility [2]. Moreover, a brake- and tyre encapsulation (patent pending) was developed, to increase the collection efficiency of emissions coming from tyres on a chassis dynamometer test bench. The particles are measured and characterised by a plethora of instruments. A condensation particle counter is used for counting the smaller particles (7 nm – 2 µm), an optical particle sizer (0.3 –10 µm) as well as low-cost sensors (0.35 – 40 µm) are used to count larger particles and determine the size distribution. An impactor and cyclones are used to collect particles by size fraction. The collected filters have been used for offline analysis with a scanning electron microscope (SEM) and energy-dispersive X-ray spectroscopy (EDS) for morphological and chemical particle characterization.

In this talk we will present the most recent research carried out at DLR in the field of NEE, with special focus on tyre emissions characterisation and how the encapsulation of tyres combined with optical sensors can help to improve the sampling performance and can thereby be a robust methodology for tyre abrasion assessment.

[1] EU Directive 2024/1257, *Official Journal of the European Union*, **2024**, Regulation - 2024/1257 - EN - EUR-Lex (accessed on 24 Jan. 2025)

[2] M. Löber, L. Bondorf, T. Grein et al. Investigations of airborne tire and brake wear particles using a novel vehicle design, *Environ. Sci. Pollut. Res.*, **2024**, *202431*, 53521–53531. https://doi.org/10.1007/s11356-024-34543-9

Approach for Measuring Volatile Tyre Particle Emissions

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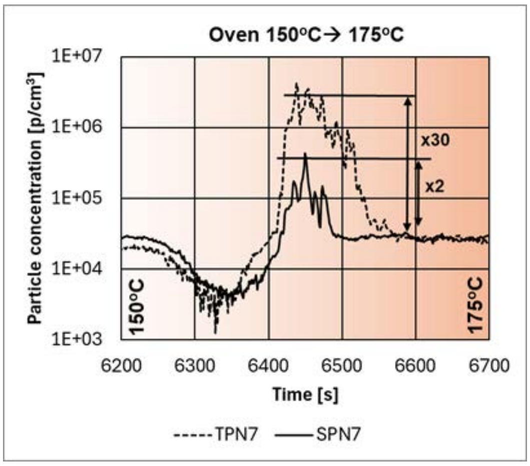
Tyre emissions are a critical source of airborne particulate matter, contributing to urban air pollution and posing potential risks [1].

This study presents findings from two experiments designed to investigate the mechanisms behind tyre particle emissions. The measurement setup included a thermodenuder to remove volatile particles and two pairs of an ELPI and a CPC for particle detection. One pair, placed after the thermodenuder, measured solid particle number, while the other, connected directly to the sampling line, measured the sum of solid and volatile particles. A preliminary oven experiment, which involved heating a small section of the tyre tread, was conducted to identify the temperature range at which volatile particles are released. The results indicated two key temperature ranges: the first between 125°C and 150°C, and the second between 150°C and 175°C. The latter range exhibited a substantial release of volatile particles.



The second experiment involved measurements on a chassis dynamometer using a novel sampling system to capture tyre particles. Based on the findings from the preliminary experiment, the thermodenuder temperature was set to 180°C. This temperature was chosen to effectively remove volatile particles while minimizing particle losses and preventing the further volatilization of semi-volatile components which may be caused by excessive heating. During these tests, volatile particles were detected only under the most demanding driving patterns.

[1] Grigoratos, T., Martini, G., Report EUR 26648, 2014, Publications Office of the European Union.

Distribution of tire wear in the environment through atmospheric transport and deposition

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When driving, the friction between the tires and the road produces particles consisting of a mixture of tire wear and road wear. These particles are called tire and road wear particles (TRWP), the tire wear in TRWP is referred to as tire wear particles (TWP). In European countries, around 1.0 to 2.0 kg of TWP are produced per inhabitant per year. In Switzerland alone, around 13,500 tons of TWP are released every year.[1] A large proportion of the produced TWP ends up in road runoff and is treated in the sewer system or in runoff treatment plants or is washed into roadside soils.[2] However, a smaller proportion of the TWP produced is suspended in the air and transported by the wind and deposited into the environment far away from roads. The amount of tire wear that is transported via the atmosphere is largely unknown due to a lack of measurements.

The typical size of TWP is above the size of inhalable particles, with several per cent of the mass of TWP produced being in the PM10 and PM2.5 size ranges. TWPs are therefore important for air quality. The release of TWP into the environment is, however, of additional concern as tire wear particles are a major source of microplastics and they contain a wide range of potentially toxic organic chemicals.

The quantitative determination of TWP in the environment is challenging due to the high uncertainties associated with the available analytical methods.[3] We present a new methodology for analyzing TWP based on pyrolysis gas chromatography mass spectrometry. The developed method has been applied to determine TWP in atmospheric deposition samples collected for one year at multiple sites in Switzerland. The sampling sites were selected to represent different land-use situations including roadsides, urban, suburban, rural and mountainous environments. These measurements are used to calculate the total amount of tire wear entering the environment every year in Switzerland through atmospheric deposition. The results are discussed in the context of the total tire wear produced and the general mass flow of TWP in the environment.

[1] Empa & wst21 (2023), Reifenabrieb als grösste Quelle von Mikroplastik – Massnahmen zur Verminderung, https://www.bafu.admin.ch/bafu/de/home/themen/abfall/mitteilungen.msg-id-97440.html.

[2] Baensch-Baltruschat, B., Kocher, B., Kochleus, C., Stock, F., Reifferscheid, G. (2020). Tyre and road wear particles - A calculation of generation, transport and release to water and soil with special regard to German roads. *Science of the Total Environment*, 752, 141939.

[3] Rauert, C., Rødland, E.S., Okoffo, E.D., Reid, M.J., Meland, S., Thomas, K.V. (2021). Challenges with Quantifying Tire Road Wear Particles: Recognizing the Need for Further Refinement of the ISO Technical Specification. *Environ. Sci. Technol. Lett.*, 8, 231−236.