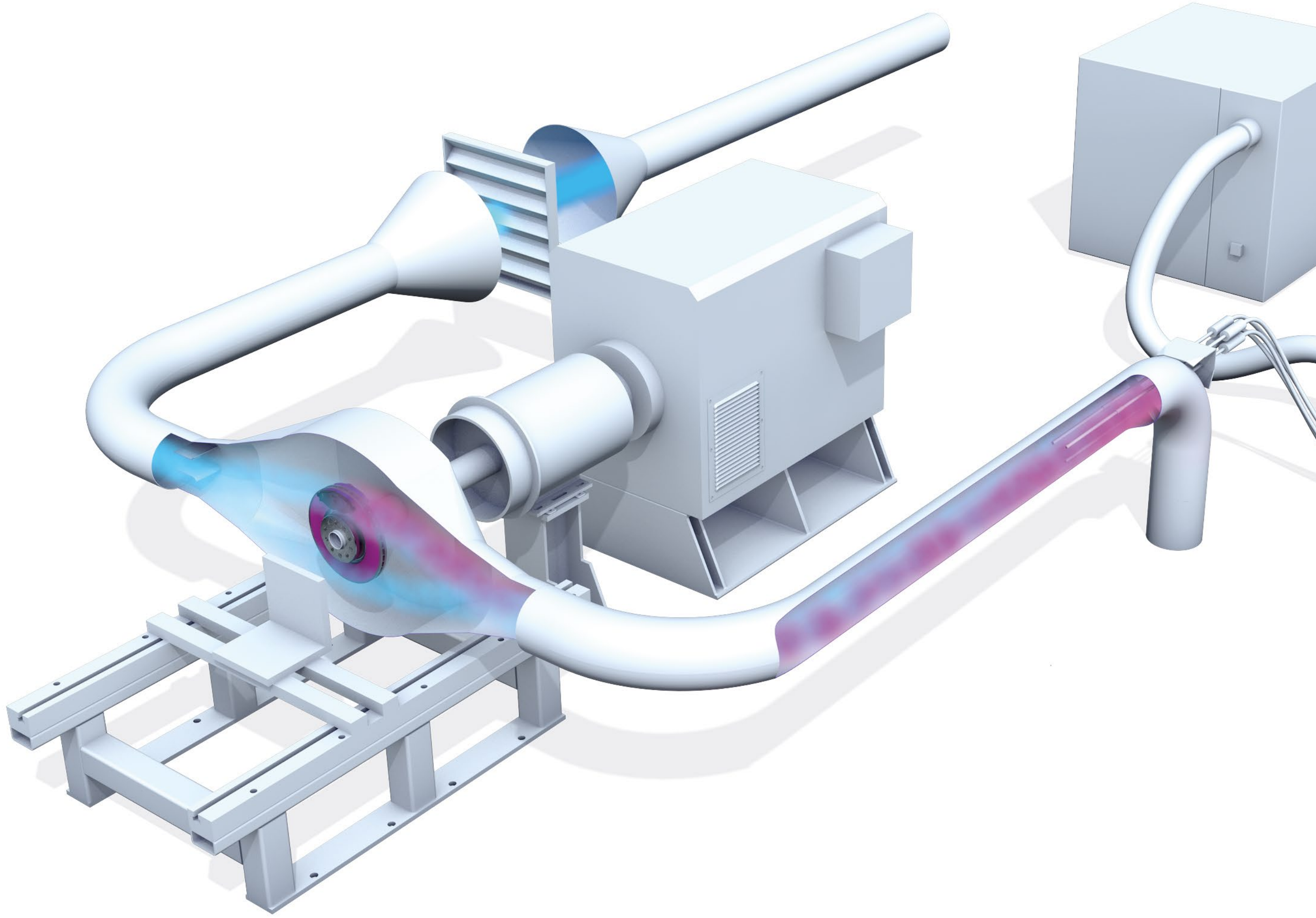
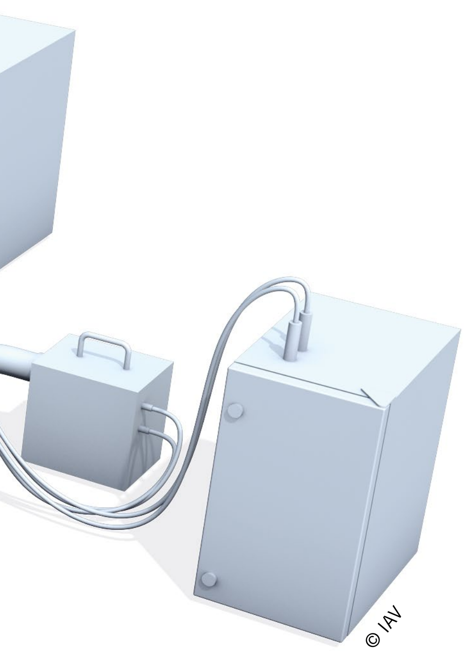


Regulation of Non-exhaust Particulate Emissions and Trends of Future Chassis Development

Non-exhaust particles sources such as brake and tire wear have already surpassed exhaust emissions of vehicles with combustion engine. As a consequence, the European Parliament has voted for a future regulation of non-exhaust emissions within the Euro 7 framework. As IAV shows, these new boundary conditions will require additional homologation and reduction measures for brakes and tires leading to new challenges for chassis development.



Fine dust particles penetrate the respiration system and pose a risk to human health. The hazardous potential depends on the particle size, morphology, and chemical composition. General statements are difficult to make [1]. Especially in urban areas vehicles contribute significantly to air pollution. Exhaust emissions have been regulated for almost three decades. As there is still no legal limit for brake and tire wear, the percentage of non-exhaust emissions has risen to about 75 % of total vehicle PM10 (particles < 10 µm) emissions [2], **FIGURE 1**.

Therefore, the working party on pollution and energy (GRPE) of the United Nations Economic Commission for Europe (UNECE) has contracted the informal Particulate Measurement Programme (PMP-IWG) to develop a method for brake emission measurement for vehicles up to 3.5 t of the segments N1 and M1. The method is summarized in a UN Global Technical Regulation (UN GTR 24) and describes all relevant boundary conditions and test parameters. The Euro 7 legislation proposes brake emissions limits of 7 mg/km for Internal Combustion Engine Vehicles (ICEVs) and Hybrid-Electric Vehicles (HEVs) as well as 3 mg/km for Battery-Electric Vehicles (BEVs) and will be the first regulation worldwide to include non-exhaust sources [4].

Tires are the biggest contributor to microplastics emissions. In Germany a total amount of 129,000 to 158,000 t/year tire wear is emitted into the environment [3]. Consequently, also the maximum tire abrasion rate (mg/km) of C1-, C2- and C3-class tires will be regulated by the Euro 7 legislation. However, test procedure and emissions factors are jet to be defined. The methodology for tire wear measurement is based on endurance testing on public roads with a total test distance of 8000 km (convoy method). The procedure requires a high logistical and financial effort and is subject to a significant number of disturbance factors (for example road surface and ambient conditions). To enhance comparability in the future also a method based on tire wear test stands is under discussion [5].

MEASUREMENT PROCEDURE FOR BRAKE DUST EMISSIONS

To ensure that environmental and load parameters are as reproducible as possible, the current method for brake dust emissions measurement is based on brake component test benches. **FIGURE 2** shows a schematic illustration of an UN-GTR-24-compliant measurement setup for brake dust emissions. It consists of a fully enclosed brake system, an air preconditioning system as well as particle measurement systems for particle number and mass. The inlet air is preconditioned (temperature, humidity) and filtered by a class-H13 filter to remove background particles. As test cycle a brake-specific Worldwide Harmonized Light Vehicles Test Procedure Brake (WLTP Brake) cycle was developed based on real world driving data. Brake wear particles are generated and injected in the surrounding cooling airflow and transported into a measurement tunnel, where isokinetic partial volume sampling is conducted. Based on the recorded/measured concentration values,

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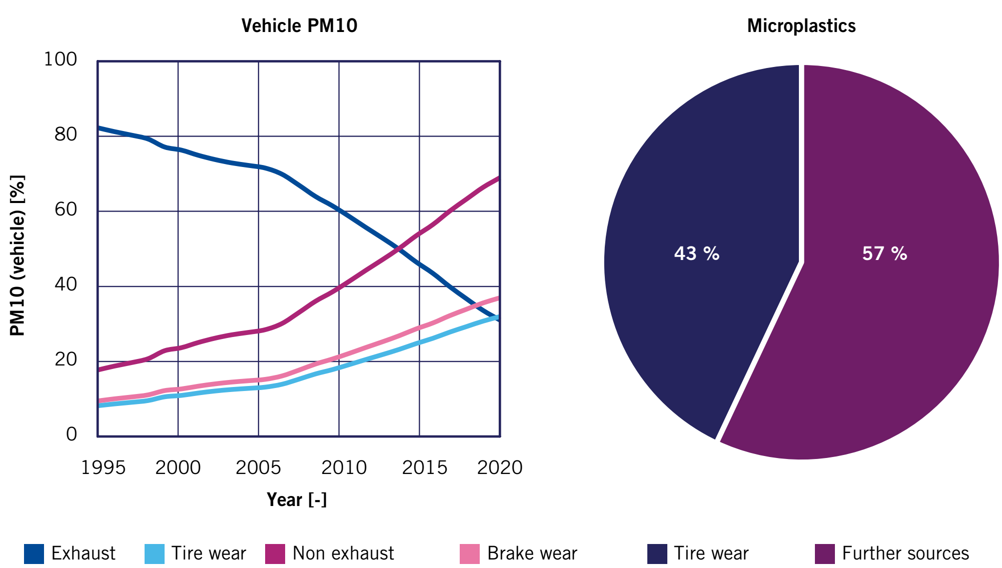


FIGURE 1 Trend of vehicle related PM10 [2] (left) and contribution of tire wear to total microplastics emissions [3] (right) (© IAV)

emission factors are calculated. For the measurement of the Particle Number (PN), Condensation Particle Counters (CPC) are applied, which are comparable to corresponding systems for exhaust emissions (UNECE-R49/83). Particle Mass (PM) emission factors are determined gravimetrically. Therefore, two filter holders with upstream pre-separators for PM2.5 (particles < 2.5 µm) and PM10 are implemented. The filters are loaded over the duration of the cycle. Afterwards, the mass gain is determined [6].

Several technical solutions for brake emissions reduction are already available today to comply with the limit values. In addition to regenerative braking strategies, alternative friction materials (coated discs or modified friction lining compounds) can reduce particle emissions significantly [7]. Furthermore, there is reduction potential by brake dust filter systems and the use of drum brakes, particularly in rear axle brake applications. It is known from previous studies that a combination of several approaches is necessary to meet the proposed limits in some specific cases [8].

INFLUENCE OF REGENERATIVE BRAKING

Especially the influence of regenerative braking must be considered with regards to its emission reduction potential. With increasing regenerative braking share the proportion of frictional braking decreases. This results in a corresponding decrease in frictional work and brake disc temperature level. However, the implementation of individual generator characteristics of HEVs and BEVs into the test bench control systems represents a significant increase in testing effort. In addition, the theoretical regeneration profile can deviate from real driving conditions. Influencing factors such as outside temperature, disc cleaning function and State of Charge (SOC) must be considered. As a starting point, fixed correction factors for different levels of electrification were implement in the UN-GTR-24 framework. Therefore, the emission factors of a standard Full Friction Brake (FFB) test cycle are multiplied with the respective coefficients to account for their reduction potential [9].

To investigate the emissions reduction of electrified vehicles, an exemplary BEV regeneration profile was implemented

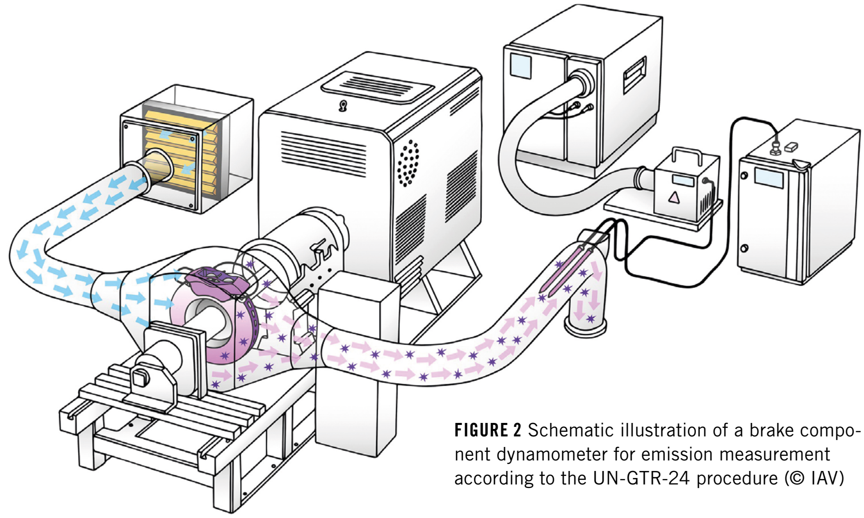


FIGURE 2 Schematic illustration of a brake component dynamometer for emission measurement according to the UN-GTR-24 procedure (© IAV)

into the control system of IAVs own UN-GTR-24 brake emission test bench. Consequently, a certain deceleration share can be taken over by the dynamometer and brake pressure is adapted according to the control quantities such as deceleration and velocity. As shown in **FIGURE 3** (purple curves) by applying the BEV regeneration profile, most friction brake applications can be avoided. However, brake emissions can occur independently from the actual friction brake application (for example due to residual braking torque). Obviously, the highly reduced number brake events cannot directly be translated into a corresponding emission reduction. The results confirm the need for the implementation of regeneration profiles within the Euro 7 legislation framework in the future. This would also reward the possibility to reduce brake emissions by optimized regeneration and control algorithms.

INFLUENCE OF PARTICLE-AIR-INTERACTION

Furthermore, measurement results can depend on the particle-flow interaction within the sampling system. With increasing aerodynamic diame-

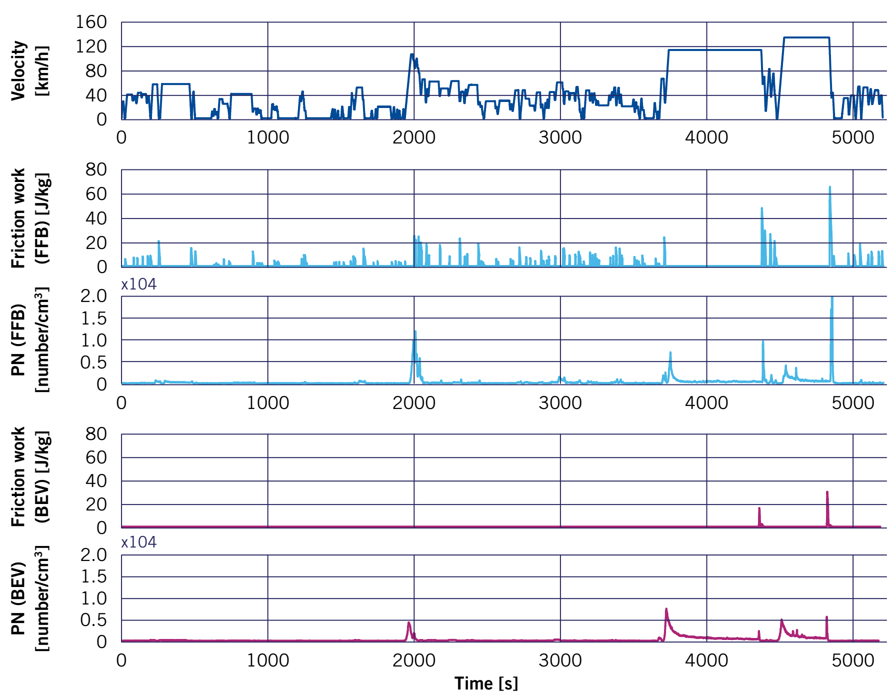


FIGURE 3 Comparison of standard FFB cycle and BEV cycle based in the implementation of a BEV regeneration profile (WLTP Brake Trip 10) (© IAV)

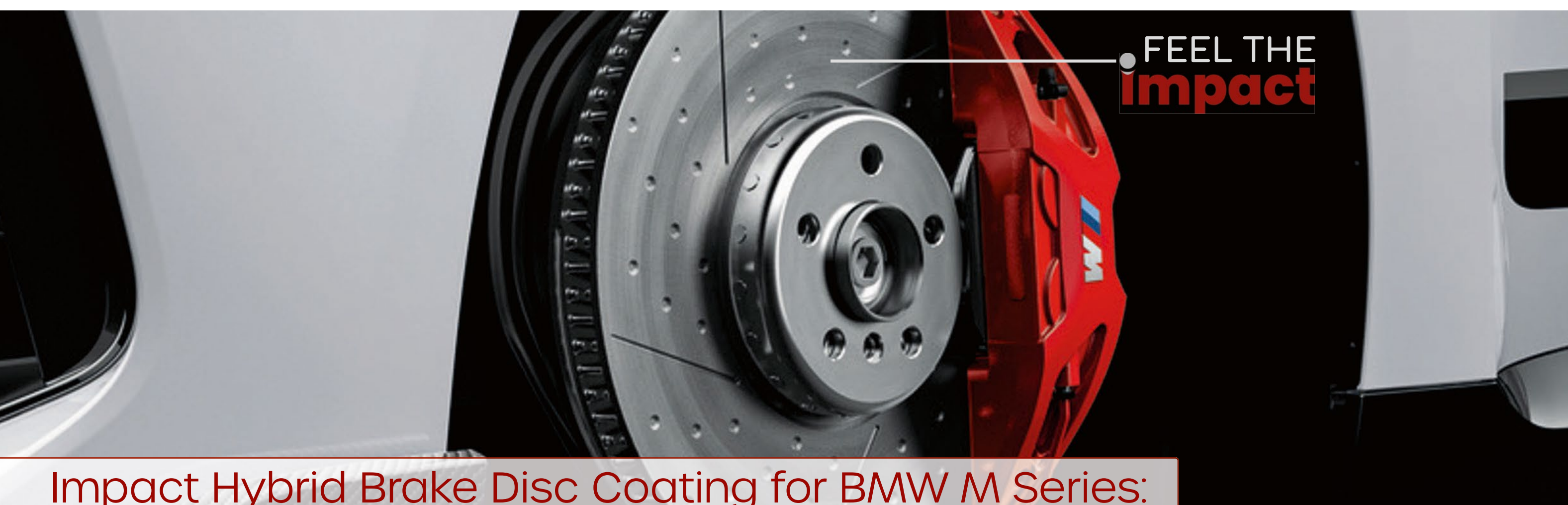
ter (>1 µm) particles are subject to inertia-dominated behavior and tend to deviate from the streamlines. Poor aerosol mixing across the sampling plane and increasing particle deposition can occur. Both parameters depend on the airflow the disc rotation speed and the shape of the brake enclosure (for example opening angle, curvature radii). Computational fluid dynamics simulation offers the possibility to describe the physical effects involved in particle-air interaction. It represents a useful tool to improve the enclosure and duct design of the UN-GTR-24 brake emission measurement setup, **FIGURE 4**. Furthermore, it can be applied for further use cases related to non-exhaust emissions. This concerns, for example, the optimization of secondary measures such as brake dust filters.

POTENTIAL OF DATA-DRIVEN EMISSION REDUCTION

In addition to the development of emission reduction measures on the hardware level (coated brake discs, filter systems) also a data driven approaches can contribute significantly to an effective protection of the environment. In a first step wear and emission data needs to be sampled and processed systematically. In a next step emission prediction models can be derived. By applying these models to real traffic scenarios, the emissions contribution by vehicle traffic can be predicted as a function of location and time. By identifying highly polluted areas, effective reduction measures can be derived to reduce the direct impact on the environment. Optimized traffic flow and vehicle control systems pose a high potential to reduce wear and particle formation due to avoidance of high longitudinal and lateral accelerations. Furthermore, wear and emission generation can be considered as a planning criterion for route planning algorithms to reduce brake and tire wear in the future.

CONCLUSION

The regulation of non-exhaust emissions by the Euro 7 legislation provides new challenges for chassis development. For the first time limits values for brake dust emissions and tire abrasion will be introduced within a legal framework. To comply with legal regulation, reduction measures will be necessary. These include alternative friction materials such as hard metal coated brake discs as well as brake particle filters.



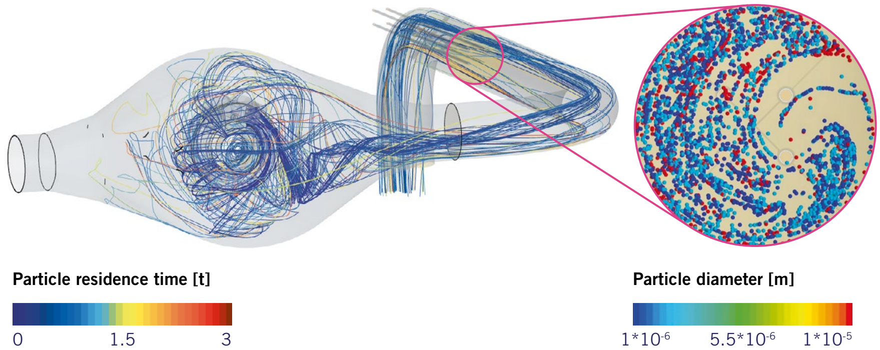


FIGURE 4 Computational fluid dynamics analysis of particle-air-interaction within an UN-GTR-24-compliant measurement setup (© IAV)

Also powertrain electrification will have a significant impact on the future emission share. While tire abrasion may increase due to increasing vehicle weights, brake emissions can be strongly reduced by regenerative braking. Within the current UN-GTR-24 procedure, fixed correction factors are intended to account for the general reduction potential of electrified vehicles. However, significantly reduced friction brake applications may not necessarily reflect in proportionally reduced emission factors in the reality. Consequently, the procedure should be extended to the application of regeneration profiles in the future. This measure would also reward the possibility to reduce brake emissions by optimized regeneration and control strategies.

The general focus should be placed on an effective protection of the population and the environment. Besides the hardware optimization intended by Euro 7, especially data-driven reduction potential should be emphasized. Systemic datacollection and modelling can provide detailed information about the occurrence of vehicle related emissions as a function of location and time. This information can be used to optimize traffic flow and avoid heavily polluted areas especially in urban environments.

Achieving maximum emission reduction with minimum additional costs, will be a major challenge for vehicle, brake, and tire industry. IAV takes on this challenge with a new test center for Euro 7 brake emission testing and virtual development methods for maximum emission reduction with minimum additional effort our customers.

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