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Multi-Element Fingerprinting of Urban Brake Wear PM2.5 Using Single Particle ICP-TOFMS Analysis

ESTHER S BREUNINGER, MADELEINE LOMAX-VOGT, FRANK VON DER KAMMER AND THILO HOFMANN

Centre for Microbiology and Environmental System Science, University of Vienna

Non-exhaust emissions from vehicles, particularly brake wear particles, are emerging as a dominant source of urban particulate pollution, yet their environmental fate remains poorly understood. While conventional bulk analysis and microscopy provide limited insights into particle composition and transformation, there is a critical need for techniques capable of characterizing individual particles at the nanoscale. This study demonstrates the application of single-particle inductively coupled plasma time-of-flight mass spectrometry (spICP-TOFMS) to investigate brake wear and road dust particles (<2.5 µm) in urban environments.

We collected 30 tire rim dust samples across Vienna, Austria as indicators of brake wear and road dust particles in diverse urban settings. Samples were prepared using optimized protocols including FL-70 surfactant stabilization (0.01-1%) and vial-tweeter sonication. The spICP-TOFMS was configured to acquire mass spectra from 14 to 254 m/z (21.739 kHz, 3 ms dwell time), enabling quasi-simultaneous analysis of up to ~175 isotopes including source-specific elements Fe, Ba, Zn, Sn, and Al. Unlike bulk methods, this technique provides particle-specific compositional data while avoiding the time-intensive nature of electron microscopy.

Analysis of individual tire rim samples revealed distinct elemental fingerprints, typically with 30-40% of particles containing three or more elements. Co-occurrence network analysis demonstrated consistent associations between brake wear-specific elements (Ba, Cu, Zr, Sn) in multi-element particles. The ability to detect these characteristic element combinations at the single particle level demonstrated the feasibility of using spICP-TOFMS for high-throughput source attribution of brake wear particles in complex urban environments.

Ongoing work combines these field-derived fingerprints with laboratory experiments investigating particle transformation under environmental and physiological conditions. By linking particle composition to nanoscale transformation processes, we aim to elucidate mechanisms controlling the environmental fate and potential impacts of these non-exhaust particles. This study highlights spICP-TOFMS as a powerful tool for investigating particle-modulated processes at the nanoscale, with broader applications in environmental chemistry and health sciences.