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A comprehensive characterisation of particles emitted by Internal Combustion Engines

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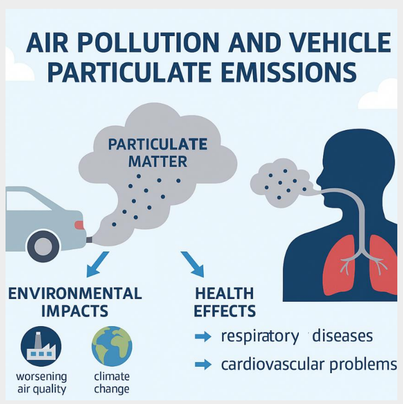
Background

Micro-metric and sub-micrometric particles emitted from modern light-duty (LDV) and heavy-duty vehicles (HDV) were characterised in the frame of the Market Surveillance of vehicle emissions (introduced in European Commission Regulation 858 (2018) [1]). This work is part of the Transport and Mobility Portfolio of the European Commission's Joint Research Centre (EC JRC). Vehicle emission tests were performed at the EC JRC Vehicle Laboratories (VELA).



Objective

Develop an **effective approach** for the physico-chemical and morphological **characterisation of fine and ultrafine vehicle-emitted particles** [1]

Scope

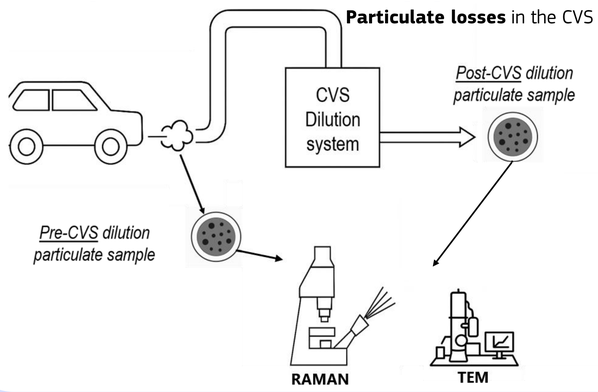
Real-world driving simulation sampling

Multiple sampling and analytical techniques

Relevance

- **Identify hazardous compounds** missed by standard methods
- Inform **future vehicle emission standards**
- Highlight **limits** of current emission **sampling protocols**
- Contribute to ongoing discussion on **public health impact**

Experimental approach



Internal Combustion Engine vehicles exhaust particulate samples collected on **filters** and **grids** at:

- **Post-CVS dilution tunnel** (according to European Commission Regulation 1151 (2017) [2])
- **Pre-CVS** dilution ***before*** (**Engine Out**) and ***after*** (**Tailpipe**) the vehicle after-treatment system

Optical microscopy coupled with **Raman spectroscopy** of particles emitted by both LDV and HDV powered by different fuels

Transmission Electron Microscopy (TEM) coupled with **Energy-Dispersive X-Ray** (EDX) analysis

- Large database of more than 300 **Raman spectra**
- Database of more than 200 **TEM images**
- **Correlative Raman–TEM analysis** of single-particles and agglomerates

Results

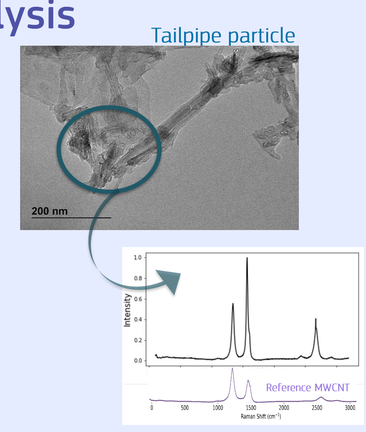
The combination of different techniques highlighted that:

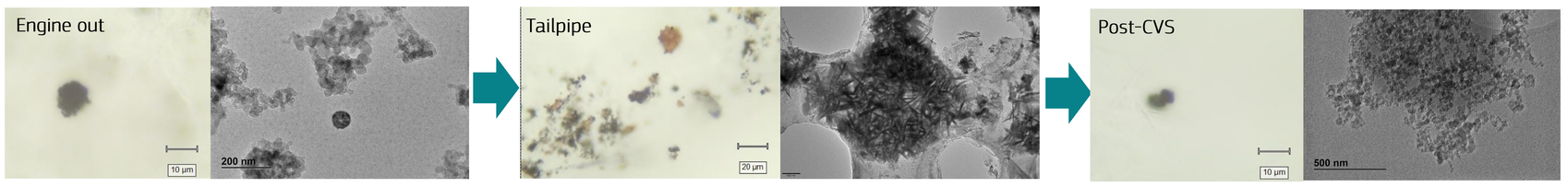
- Particulate emitted at the **engine out** stage mainly consists of black carbon (BC).
- BC in the form of fractal-like spherules aggregates or more compact oval particles + other types of particles can be detected at the **tailpipe** (elongated carbon structures, iridescent/red ovals, needle-like Cu aggregates, etc.)
- **CVS**-diluted samples, contain, as expected, much fewer particles, essentially consisting of BC again.

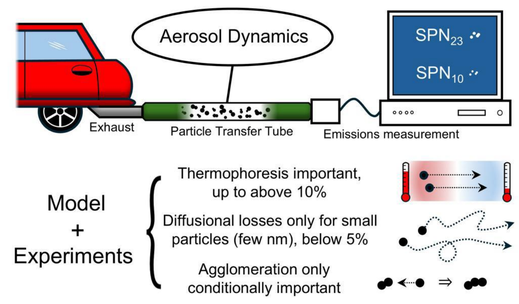
FOCUS: correlative Raman-TEM analysis

A correlative Raman-TEM approach was used to **link Raman spectral signatures with the morphology of individual particles** in selected samples.

- **Raman-identified particle** (on filter) with Multi-Walled Carbon Nanotube-like (MWCNT) spectrum
- Point sample extracted and deposited on TEM grid
- **TEM on the extracted sample** (on grid) confirmed CNT structure
- Inverse correlative TEM-Raman analysis explored (on TEM grid) at single-particle level







Conclusions and outlook

- Raman spectra and TEM images show **black carbon** (defective graphite) as the dominant particulate component.
- **Other components** include carbon nanostructures, iron and copper oxides observed in **TAILPIPE samples only**.
- **Particle losses** in the dilution system are relevant and can depend on morphology and composition.
- **Correlative Raman–TEM analysis** at single-particle level enabled spectral–morphological identification.
- This **comprehensive particulate characterization** could be extended to the study of non-exhaust particles such as those from tyre and brake wear.

15%-20% particulate loss in the dilution system mainly due to thermophoresis and diffusion [3].

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References

[1] *Ferrarese, C. et al. Analysis of sub-micrometric particulate emitted by different types of internal combustion engines: a Raman microscopy and a Principal-Component Analysis study. Environ Sci Eur (2026). https://doi.org/10.1186/s12302-025-01271-x*

[2] *EC, Commission Regulation (EU) 2017/1151 (2017)*

[3] *Kanoutos, K. et al, (2025). Aerosol-dynamics experiments and simulations of vehicle exhaust emissions, Aerosol Science and Technology, 59:12, 1498-1516, https://doi.org/10.1080/02786826.2025.2531214*