SUREAL-23

UNDERSTANDING, MEASURING AND REGULATING SUB-23 NM PARTICLE EMISSIONS FROM DIRECT INJECTION ENGINES INCLUDING REAL DRIVING CONDITIONS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 724136

Overview

- Motivation
- Concept
- Technology and instrumentation development
- Test campaign results
- Project achievements and remarks

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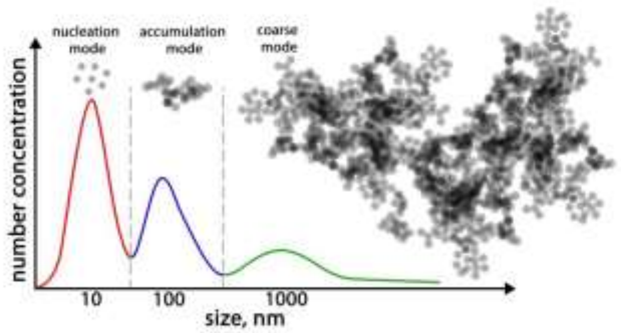
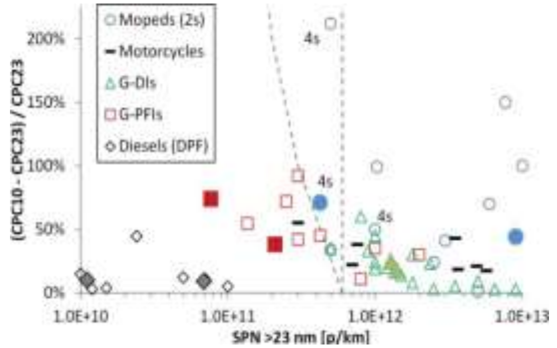
Motivation

- Ultrafine particles are considered responsible for adverse health effects due to their high surface to mass ratio.
- Current European legislation sets a solid particle number (PN) limitation for particles larger than 23 nm.
- Large fraction of emitted particles lie in the sub-23 nm size region.
- Reduce the lower size limit without affecting measurement uncertainty and reproducibility.





[1] *Science of the Total Environment 408:5106–5116 (2010).*
[2] *Aerosol Sci. Technol., 42:528–43 (2008).*
[3] *Aerosol Sci. Technol., 51:5, pp. 626-641 (2017).*
[4] *Inhal Toxicol., 16(6–7):437–45 (2004).*

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The concept

Focus

- The ***SUREAL-23*** project focuses on the particles, **smaller than the current regulation cut-off limit of 23 nm**, emitted from Light Duty engines (Diesel, Gasoline and CNG).

Objectives

- **Complement and extend** existing instrumentation for particles below 23 nm.
- **Characterize** in detail the nature of the particulate emissions below 23 nm.
- **Support future emissions** compliance through technical developments in RDE.

Innovation

- **Size and composition** analysis methods suitable for transient engine emissions.
- **Novel instrumentation** for measuring aerosol particles below 23 nm, providing backward compatibility with established PN measurement technology.
- Enhancement of instrument specifications to allow operation with **less demanding sample conditioning** requirements.
- Integration of the most suitable components of the extended sub-23 nm measurement toolset into **PEMS** and verification in real driving conditions.

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Measurement technology development

Size classification

- Advanced DMA (1-30nm, High temp.)

PN measurement

- Diffusion charger for sub-23nm (>10nm, High temp.)
- Sizing CPC (PN + Size distribution, Low particle losses)

Composition analysis

- Multi-wavelength photoacoustic spectroscopy
- UV photoelectric ionization

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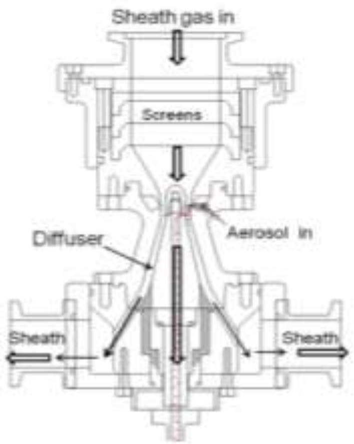
The Advanced Half-Mini DMA

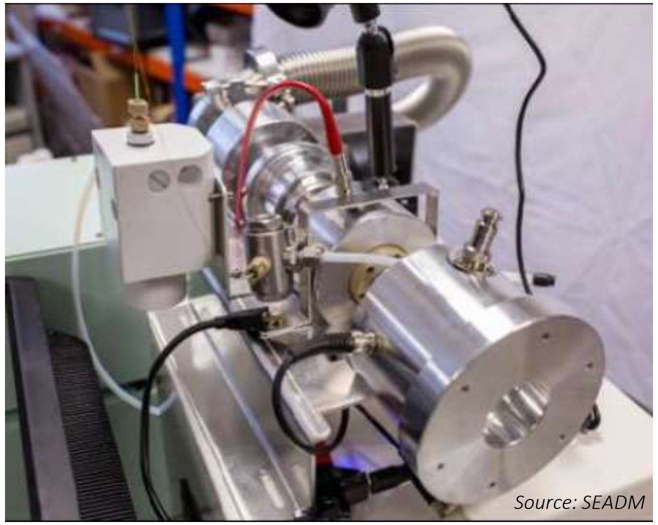
- **Half-Mini DMA** is a commercially available instrument with high-resolution size classification in the range 1-15 nm
- Advancement during the project:
  - High resolution in extended size range (5–30 nm)
  - Accurate hot operation up to 200 °C
  - Fast response time (down to 1 s)

The design

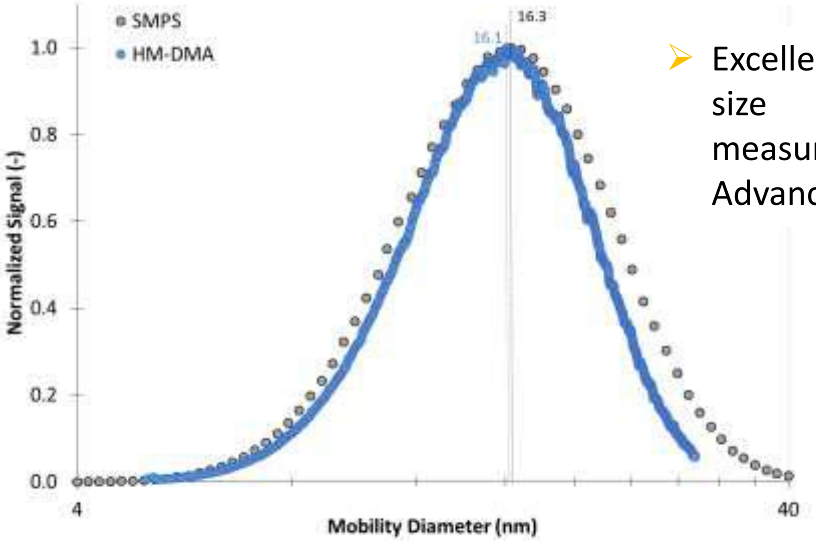


Fernández de la Mora J., Kozlowski J., *J. of Aerosol Science 57 (2013) 45–53*

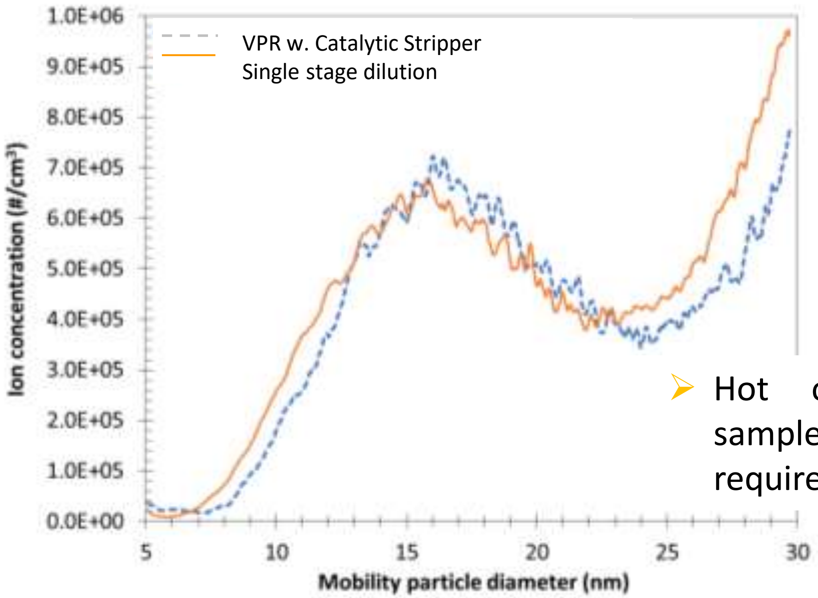
The prototype



Source: SEADM



- Excellent agreement of size distributions measured by SMPS and Advanced HM-DMA.



- Hot operation reduces sample conditioning requirements.

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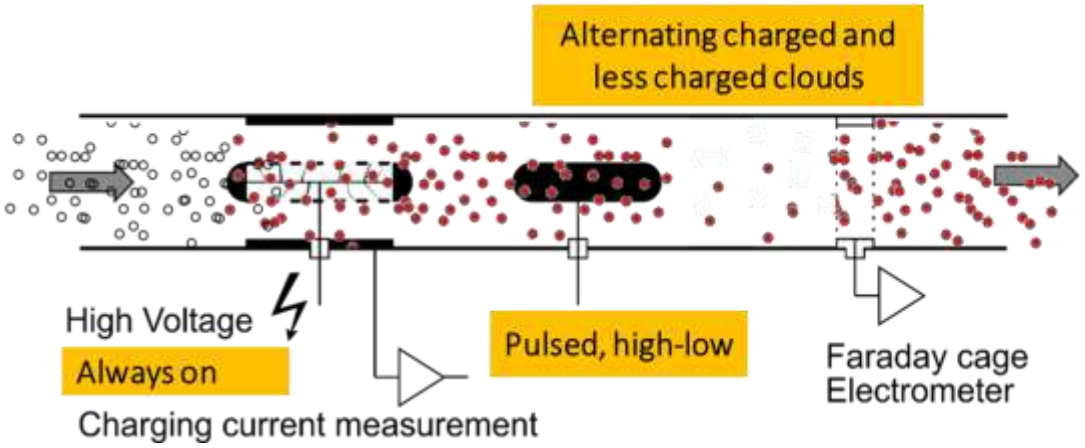
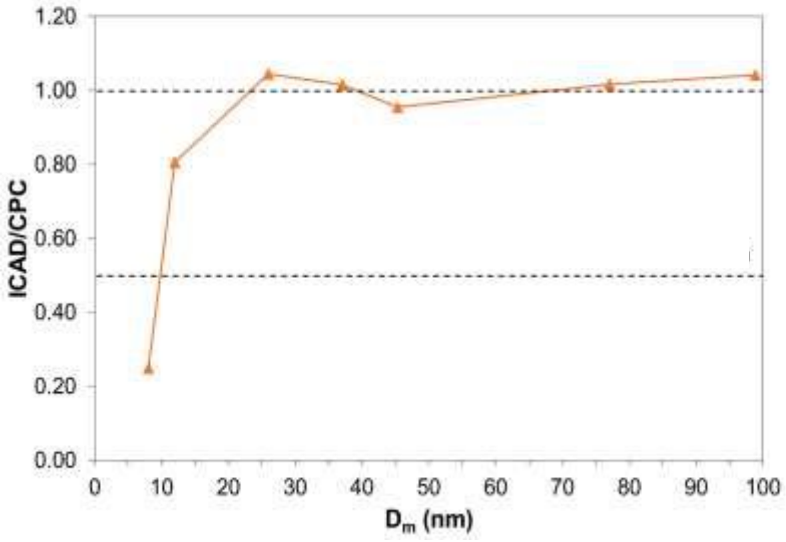
ICAD: Induced Charge Aerosol Detector

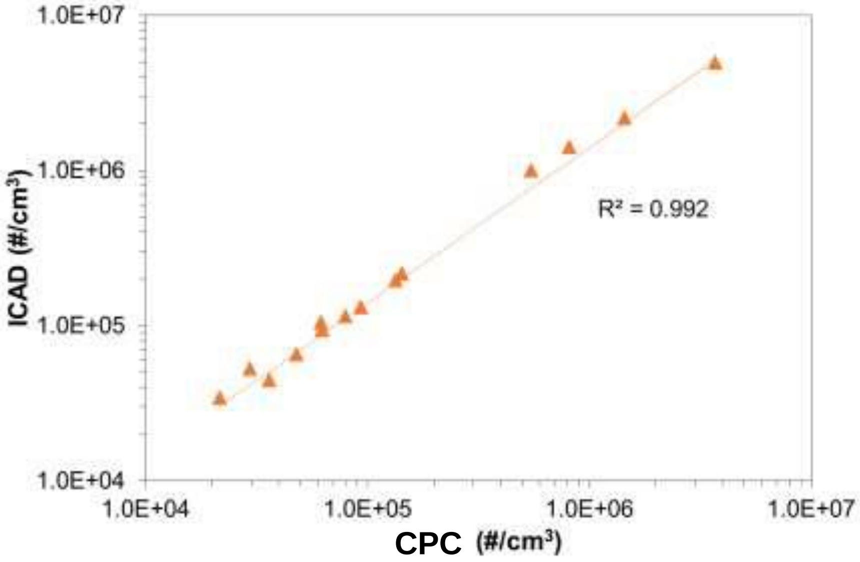


Objectives

- Optimize settings to achieve d_{50} =10 nm.
- High temperature operation at 180 ºC.
- Increase robustness and reliability for PEMS applications.



- Counting efficiency is similar to a CPC and d_{50}=10 nm.



- Excellent linearity between ICAD and CPC.

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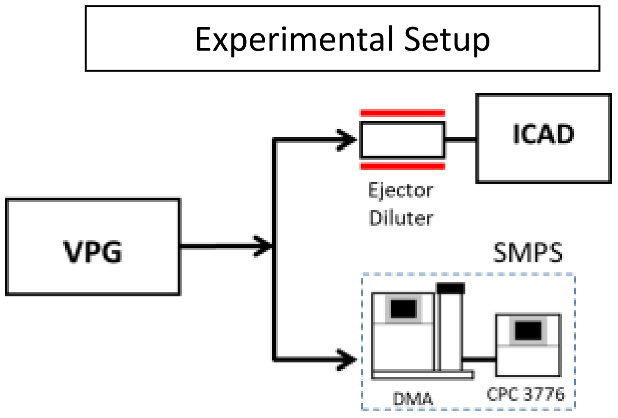
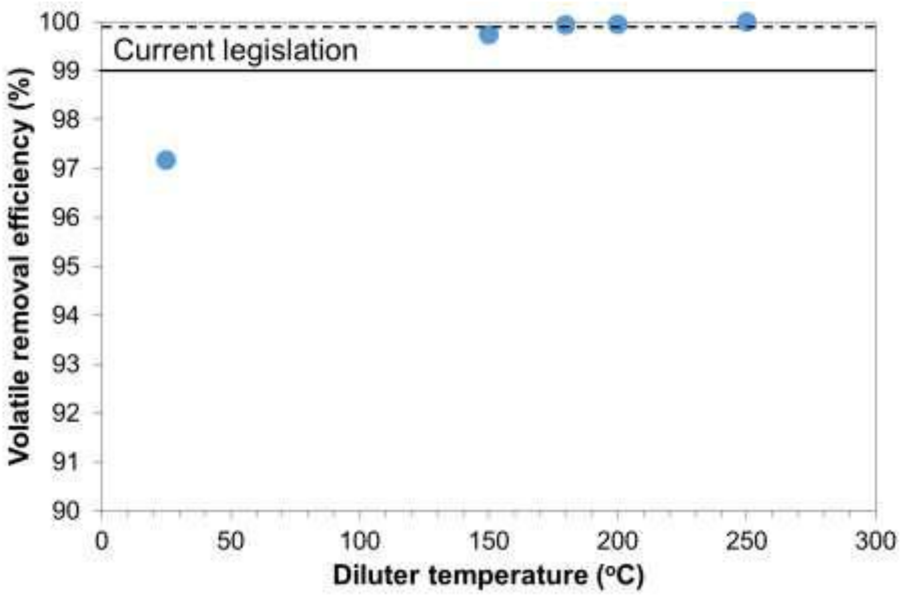
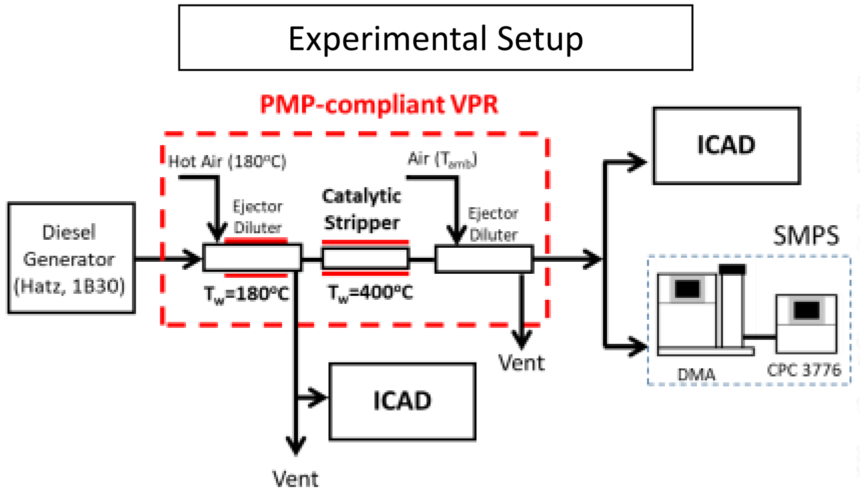
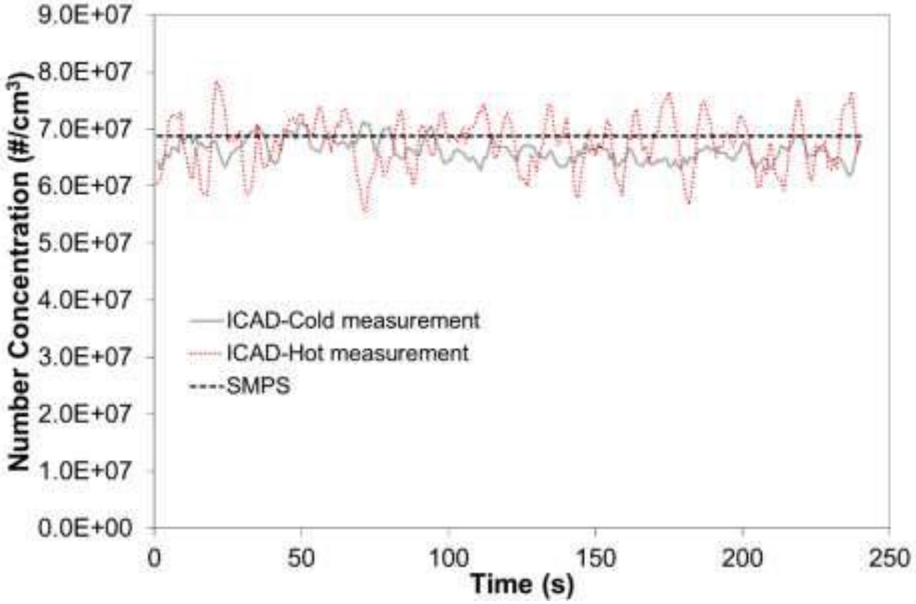
Automotive ICAD hot operation





- The proposed single hot dilution setup is tested with tetracontane particles with $D_m \geq 30$ nm and shows removal efficiency >99% for T≥150°C.





- Hot and cold ICAD measurements are in excellent agreement with SMPS, 1.9% and 3.7% respectively.

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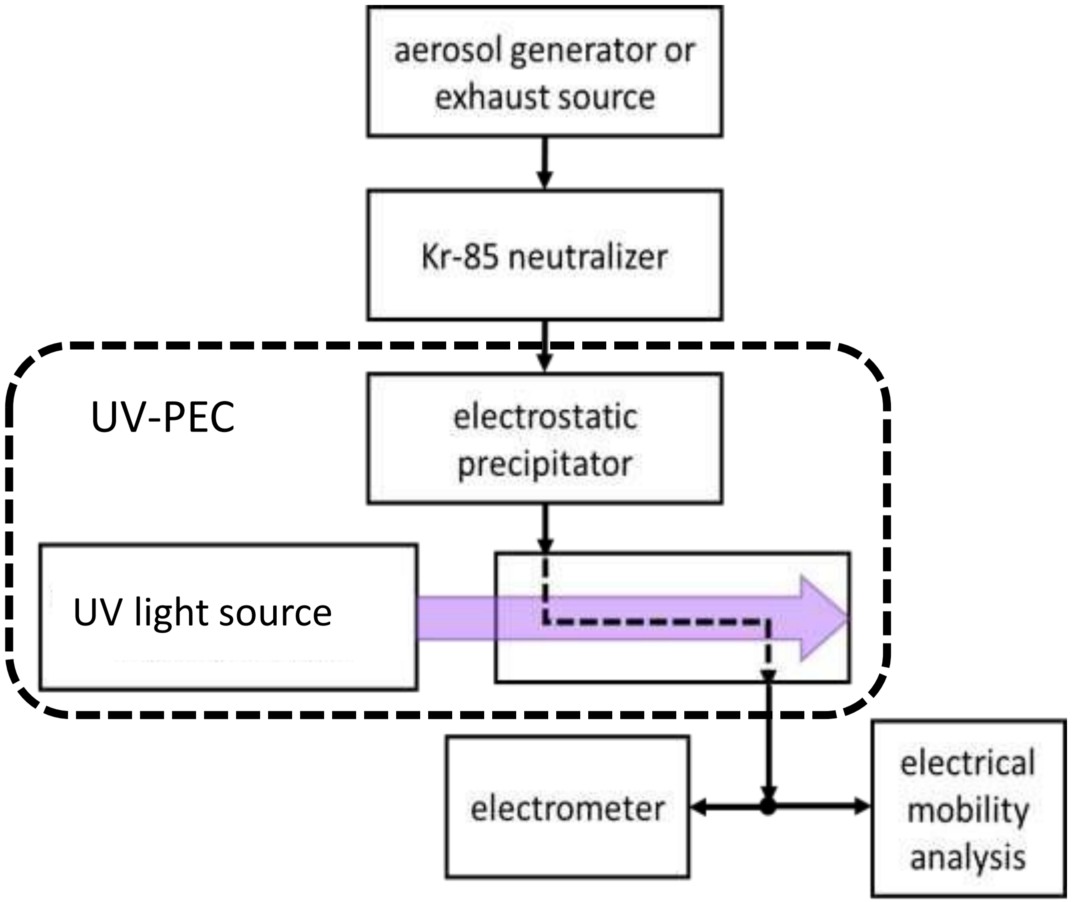
UV Photoelectric Charger (UV-PEC)

- When an aerosol is irradiated with ultraviolet (UV) light of energy above the photoelectric threshold of surface material, electrons may be emitted/ particles acquire a positive charge.
- The photoionization threshold is strongly **material dependent**. This can be used to distinguish the chemical fingerprint of condensed matter on the exhaust particles.
- Basic components:
  - Electrostatic precipitator
  - UV light source
  - Ionization chamber
  - Ion trap (Optional for sub-23 nm particles)
  - Measurement device (Electrometer, CPC, SMPS)



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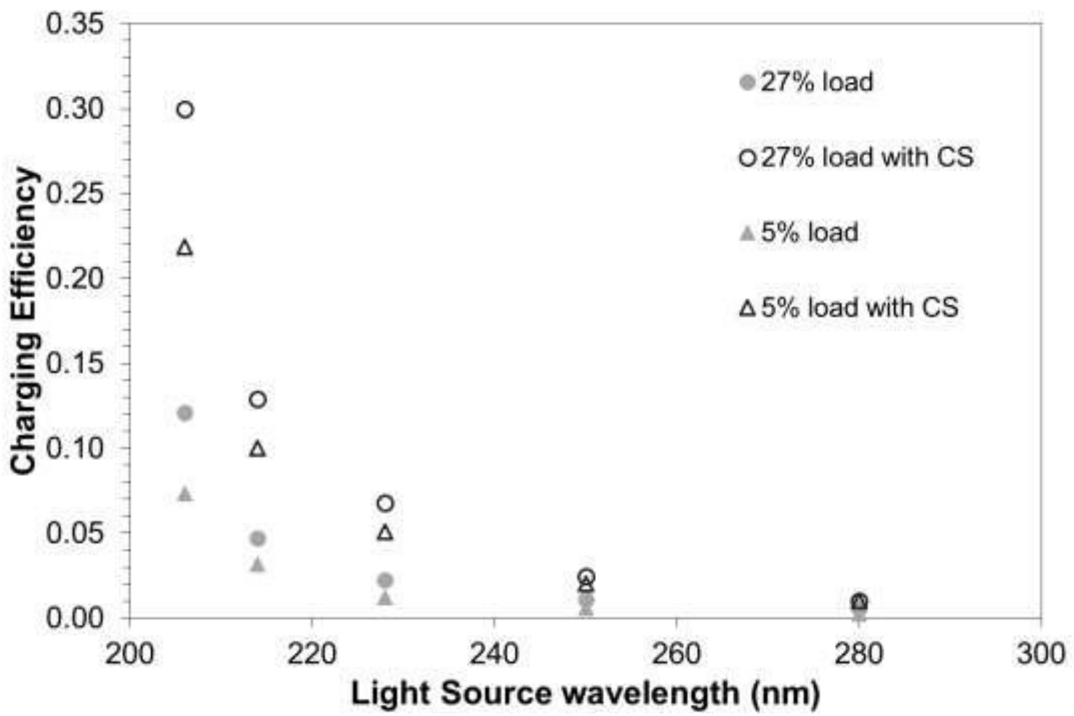
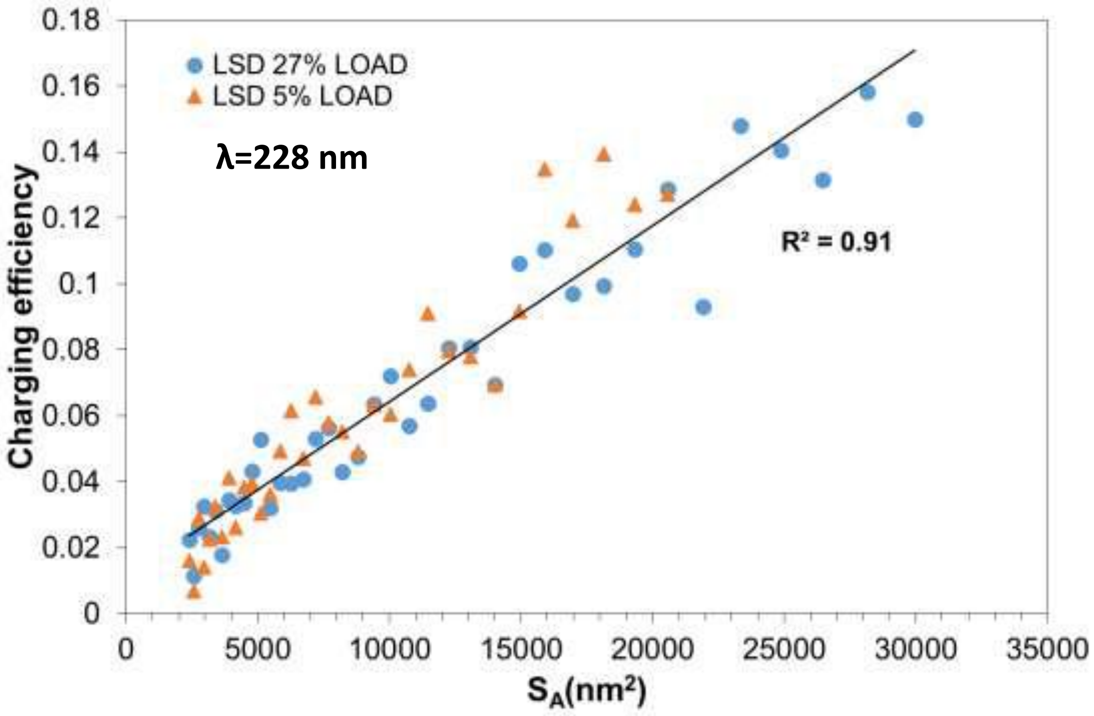
UV-PEC at the Diesel engine exhaust





- The higher charging efficiency is observed at λ=206 nm (wavelength of PAHs).
- Charging efficiency and thus, PAH content, has a linear relation with the active surface area, S_A.

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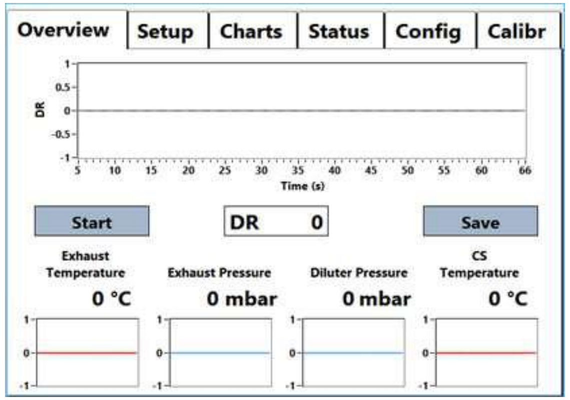
Sampling and Conditioning System

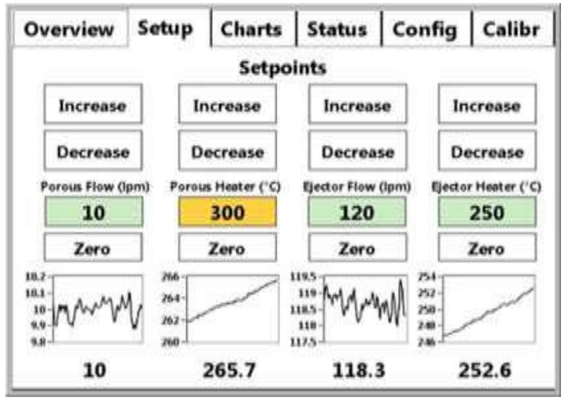
Design parameters

- Two-stage dilution, with adjustable dilution ratio (DR=30-120).
- Porous tube diluter as first stage to minimize sub-23 nm particle losses.
- Ejector diluter as a second stage to maintain stable DR under transient engine operation.
- Option for catalytic stripper/evaporation tube installation between the two dilution stages.

Objectives

- Minimum particle losses
- Artefacts elimination (with CS)
- Dilution ratio stability and flexibility





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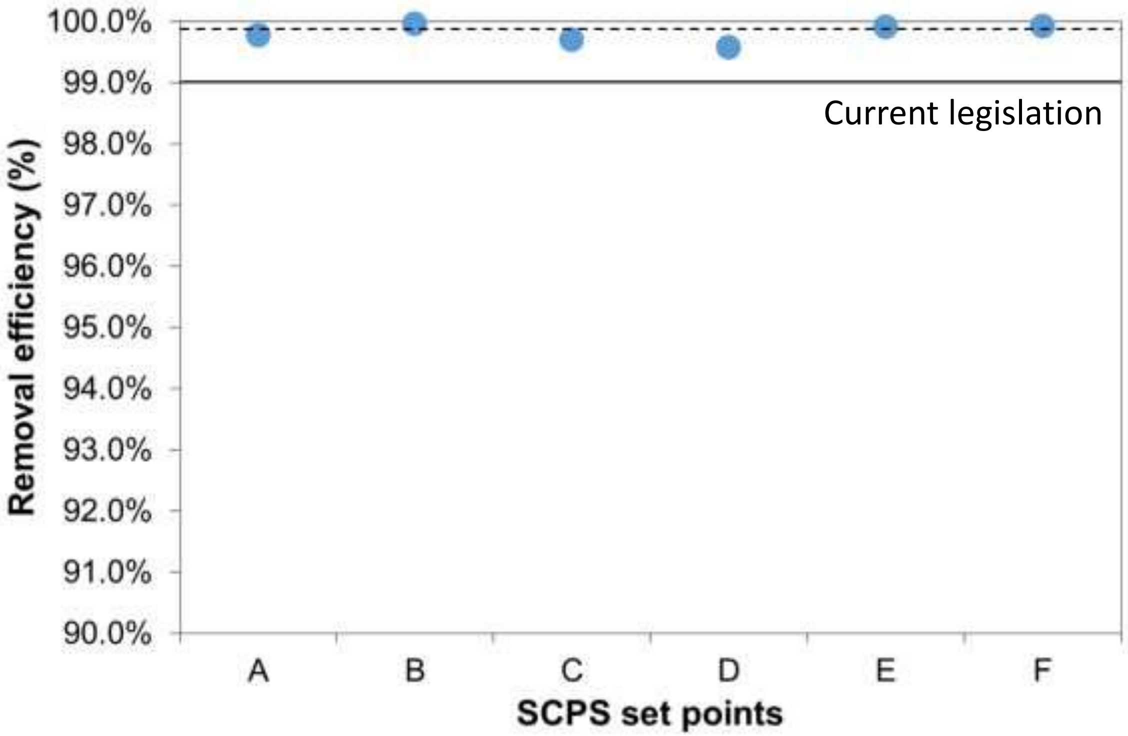
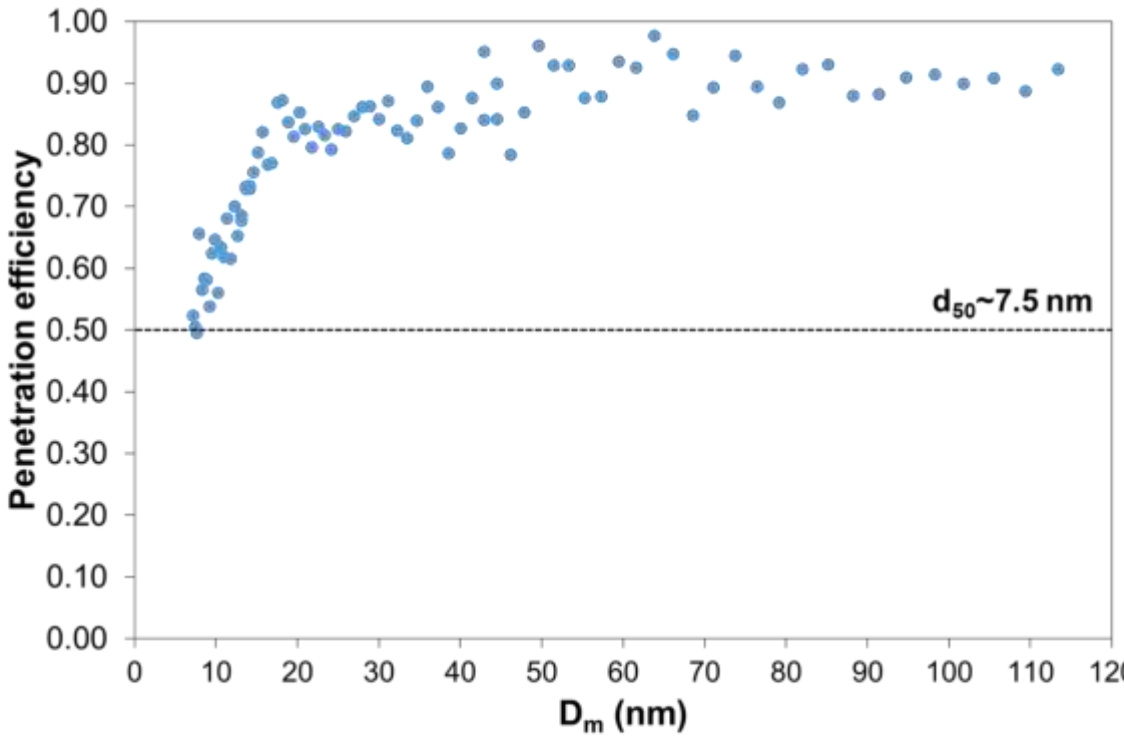
Sampling and Conditioning System evaluation





- The tetracontane particle removal is tested in a wide DR range (30-60).
- $>10^6$ (#/cm^3) tetracontane particles are removed with >99% efficiency in all tested set points.
- d_{50}=7.5 nm.
- Particle number concentration reduction factor (PCRF) including $PCRF_{15}$ is 1.15±9%.

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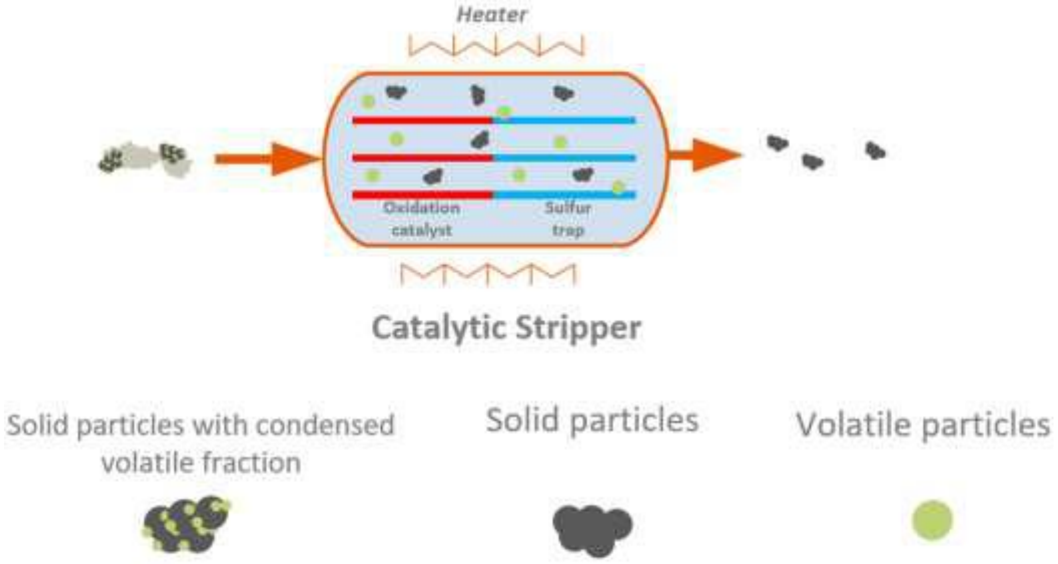
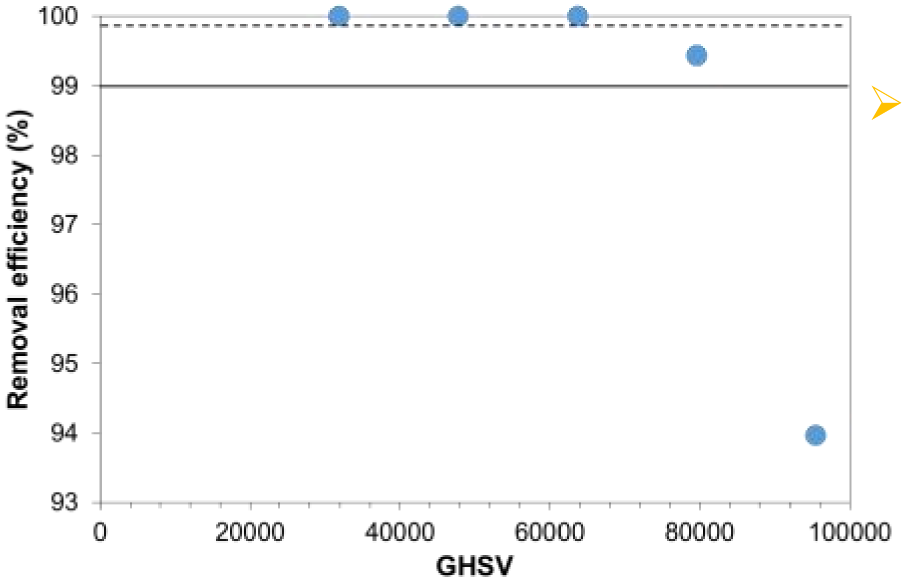
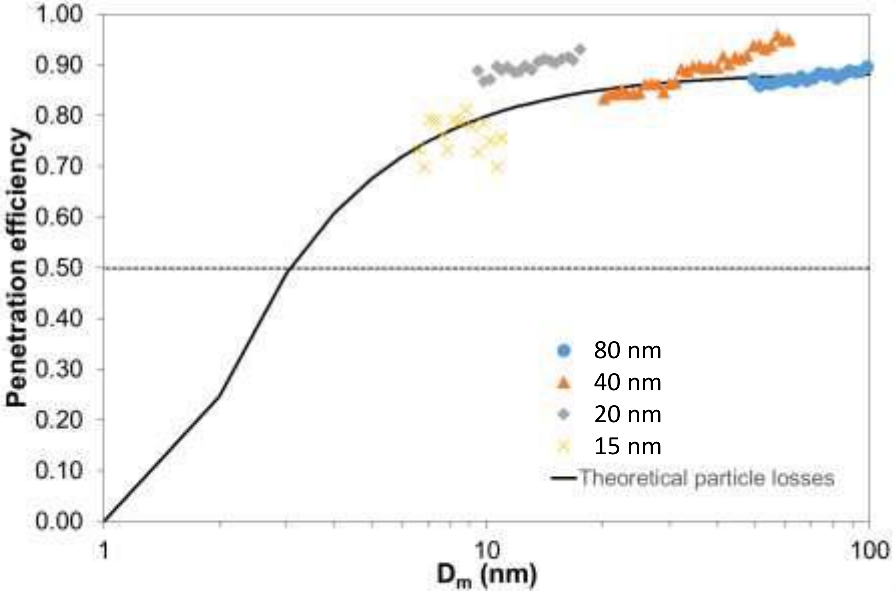
Catalytic stripper





- Oxidation efficiency >99% for monolith space velocities up to 80000 (h^{-1}).

- **Catalytic Stripper (CS) technology**
  - Dual-function monolithic reactor for volatile particles oxidation and sulphur trapping.
  - Compactness
- **CS evaluation includes:**
  - Oxidation efficiency (~106 (#/cm3) tetracontane particles, C40H82)
  - Sulphur adsorption (23 ppm SO2)
  - Solid particle penetration (CAST-generated particles)



- Solid particle penetration was tested with catalytically pre-treated CAST generated particles.

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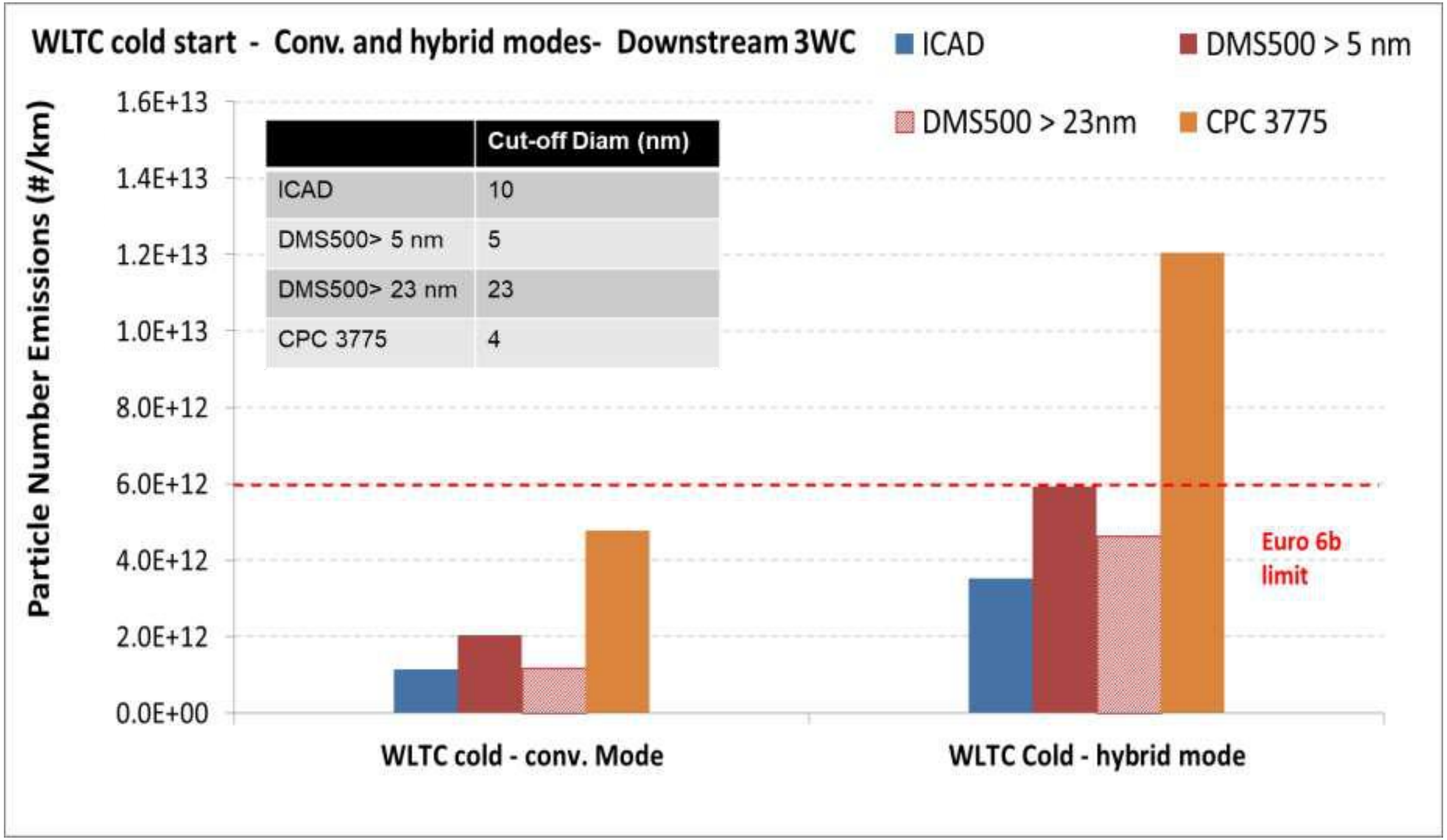
Effect of Hybrid Operation



	Cut-off Diam (nm)
ICAD	10
DMS500> 5 nm	5
DMS500> 23 nm	23
CPC 3775	4

- Simulation of hybrid operation on test bench.
- Last-generation four-stroke, GDI engine with turbocharger, 1.3L.
- Equipped with 3WC and no GPF.
- Standard European fuel E10.

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Vehicles tested

GDI, Euro 6d, GPF
(Alfa Romeo Giulietta)

CNG DI, TWC
(FIAT 500L prototype)

Diesel, DOC, Euro 6d, SCRoF+SCRuF
(Alfa Romeo Stelvio)

PFI+GDI, Euro 6b
(Audi A4)

GDI, Euro 6d - temp, GPF
(Renault Kadjar)

GDI, Euro 6d - temp, GPF
(Kia Niro Hybrid)

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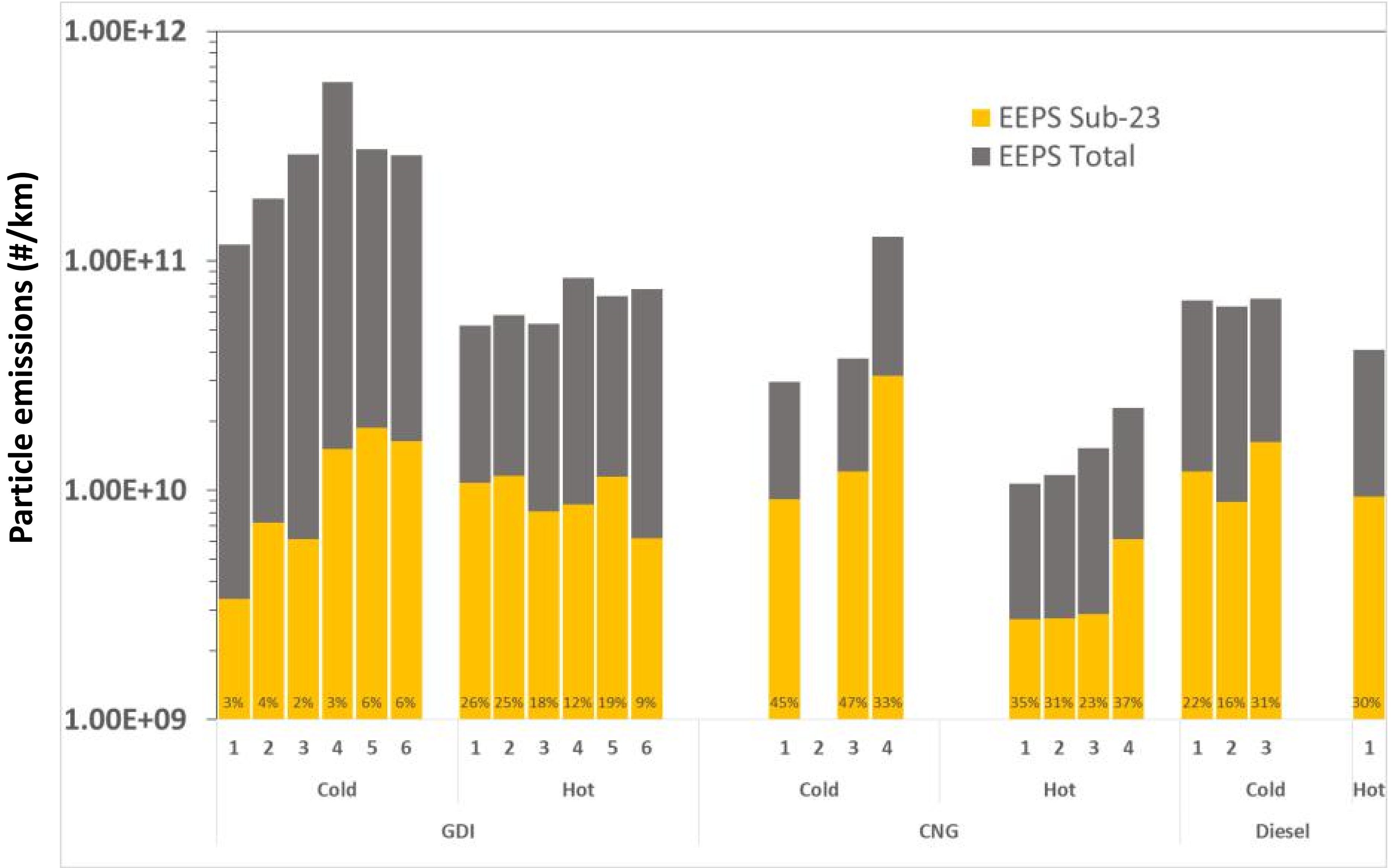
Particle emissions of different vehicles/engine technologies



- GDI: During cold-start cycles, particle emissions are high.
- CNG: Total number of emitted is low, especially during hot-start cycles.
- CNG: Percentage of sub-23 particles can be significant.

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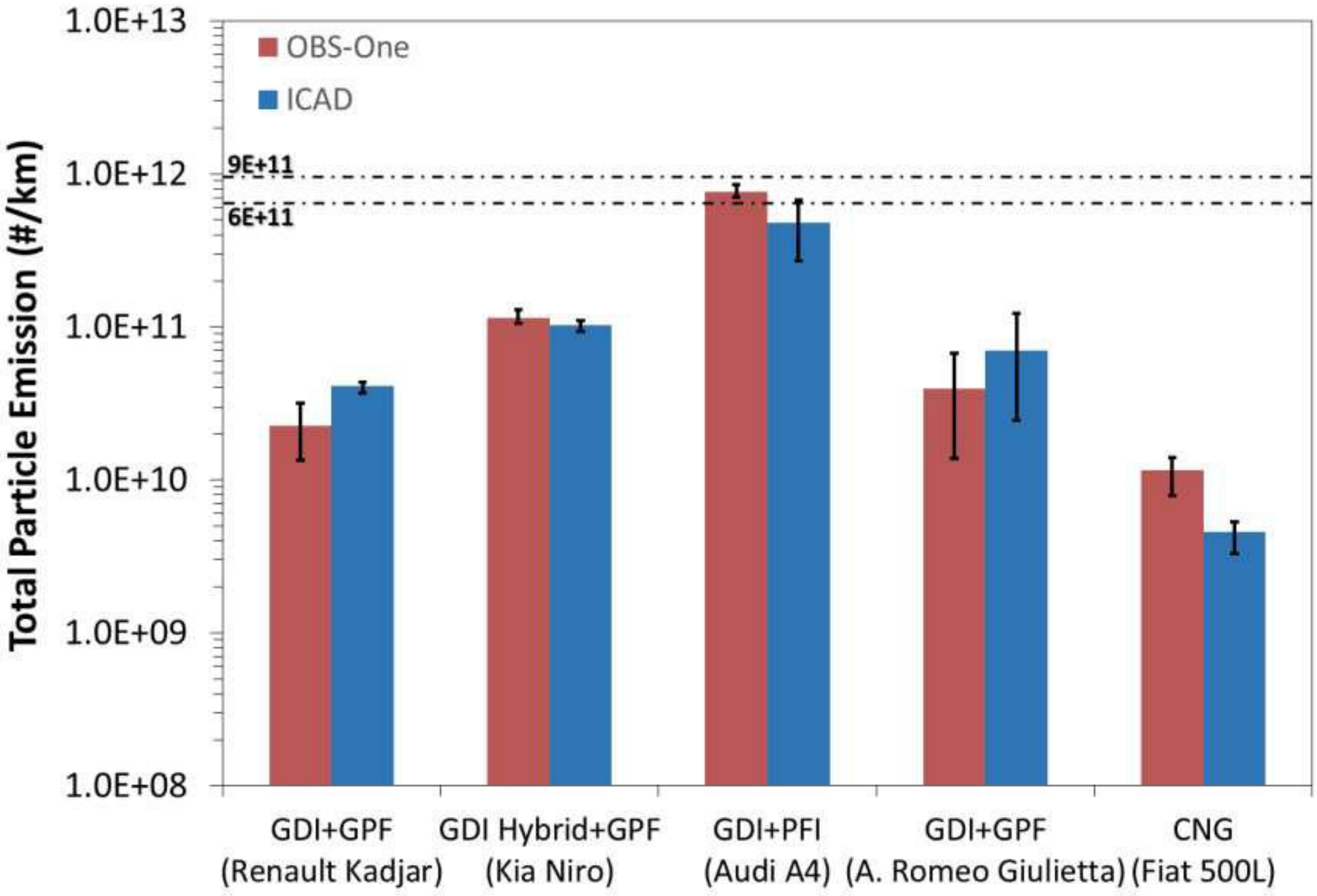
RDE measurement results



- Error bars show the minimum and maximum measured values of the 3 trips.
- All vehicles emitted lower number of particles than the EU limit.
- GPF should eliminate sub-23 particles.

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Main Achievements

- **Innovative instrumentation:**
  - Advanced HM-DMA
    - ✓ Exceptional resolution and fast response.
    - ✓ Capable of measuring hot aerosol sample (minimal sampling/conditioning requirements).
  - Automotive ICAD
    - ✓ Light, compact and with low power requirements.
    - ✓ Capable of measuring hot aerosol sample.
  - Sizing-CPC
    - ✓ Novel instrument, combining particle size with particle number concentration measurements.
  - Particle composition instruments
    - ✓ Particle charging using photoelectric principal shows potential to identify PAH content.
    - ✓ Photoacoustic based instrument aims at identifying different particle components (e.g. metals).

- **Advanced Sampling System:**
  - Design based on a porous-tube and ejector diluter, including a Catalytic Stripper (CS), with minimal particle losses and excellent volatile and sulphur removal efficiency.

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Remarks

GDI:

- Emit high concentrations of particles in the range of 10 to 40 nm. Sub-23 particles therefore have to be considered.
- If they are equipped with state of the art GPF (as efficient as DPF) these particles will also be removed efficiently and again it makes not much difference whether the limit is 10 or 23 nm.
- Currently used GPF often have much lower efficiencies. The contribution of <23nm particles then may be significant.
- This becomes even more important if engine optimization should enable meeting the limits without GPF.

DIESEL:

- Soon most diesel vehicles should be equipped with very efficient DPF's (eff. >99%) that will remove solid sub 23nm particles even more efficiently.
- As long as the filter works properly, there is no need to care for measuring small (solid) particles. Otherwise the >23nm emission will be too high to pass a test.
- Periodic emission measurements is much more important than changing the number limit or cut-off size.

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Thank you for your attention!

SUREAL-23

SUREAL-23 FINAL WORKSHOP 10 DECEMBER 2019, IFPEN, LYON FRANCE

Measuring and regulating sub-23 nm particle emissions from light duty powertrains: Questions and answers from 3 years of H2020 research

Co-financed by the European Union
Connecting Europe Facility

SUREAL-23 project has received funding from the European Union's Horizon 2020 research and innovation programme under H2020: Green Vehicle 2016 Technologies for low emission light duty powertrains (GV-02-2016) under grant agreement No 724136.

For more details, visit the website of Sureal-23 project (sureal-23.cperi.certh.gr)

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