AVL List GmbH (Headquarters)

GTR 15 modifications for 10 nm PN measurements

Investigations performed at AVL

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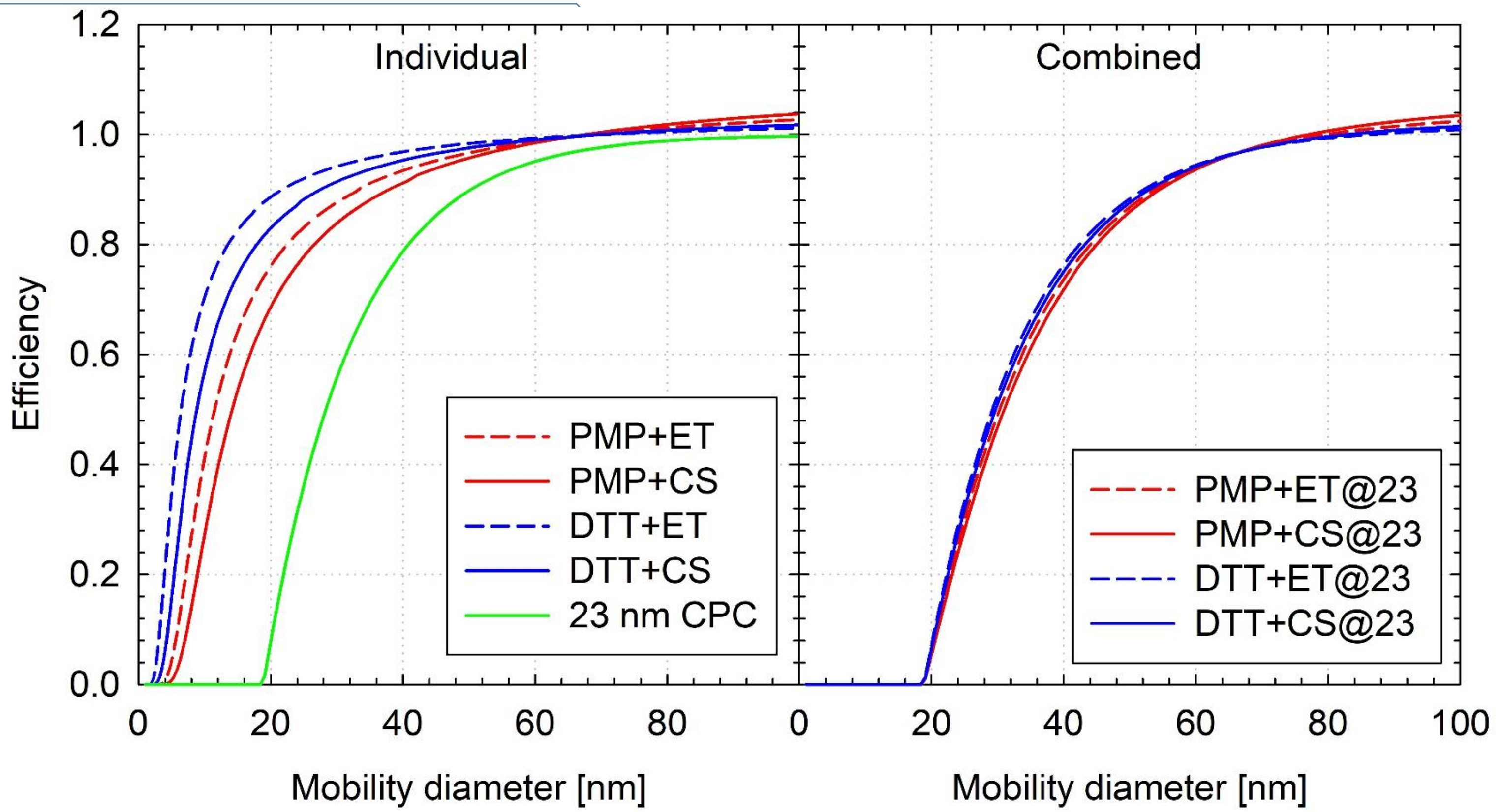
Public

Contents

- Overall counting efficiency and limiting components for 23 and 10 nm PN systems.
- Experimental investigations on:
  - the influence of CS on 23 nm PN measurements of vehicle exhaust.
  - the applicability of polydisperse checks for 23 and 10 nm PN systems.
  - the relative effect of calibration material for 10 and 23 nm CPC counting efficiencies.
  - the linearity performance of modern CPC designs.
- DTT investigations on the potential offered by AVL's CS in suppressing H_2SO_4 nucleation.

Contribution of individual components on the overall detection efficiency of 23 nm systems

Sampling system penetrations are corrected for the average losses at 30, 50 and 100 nm as defined in the regulation.



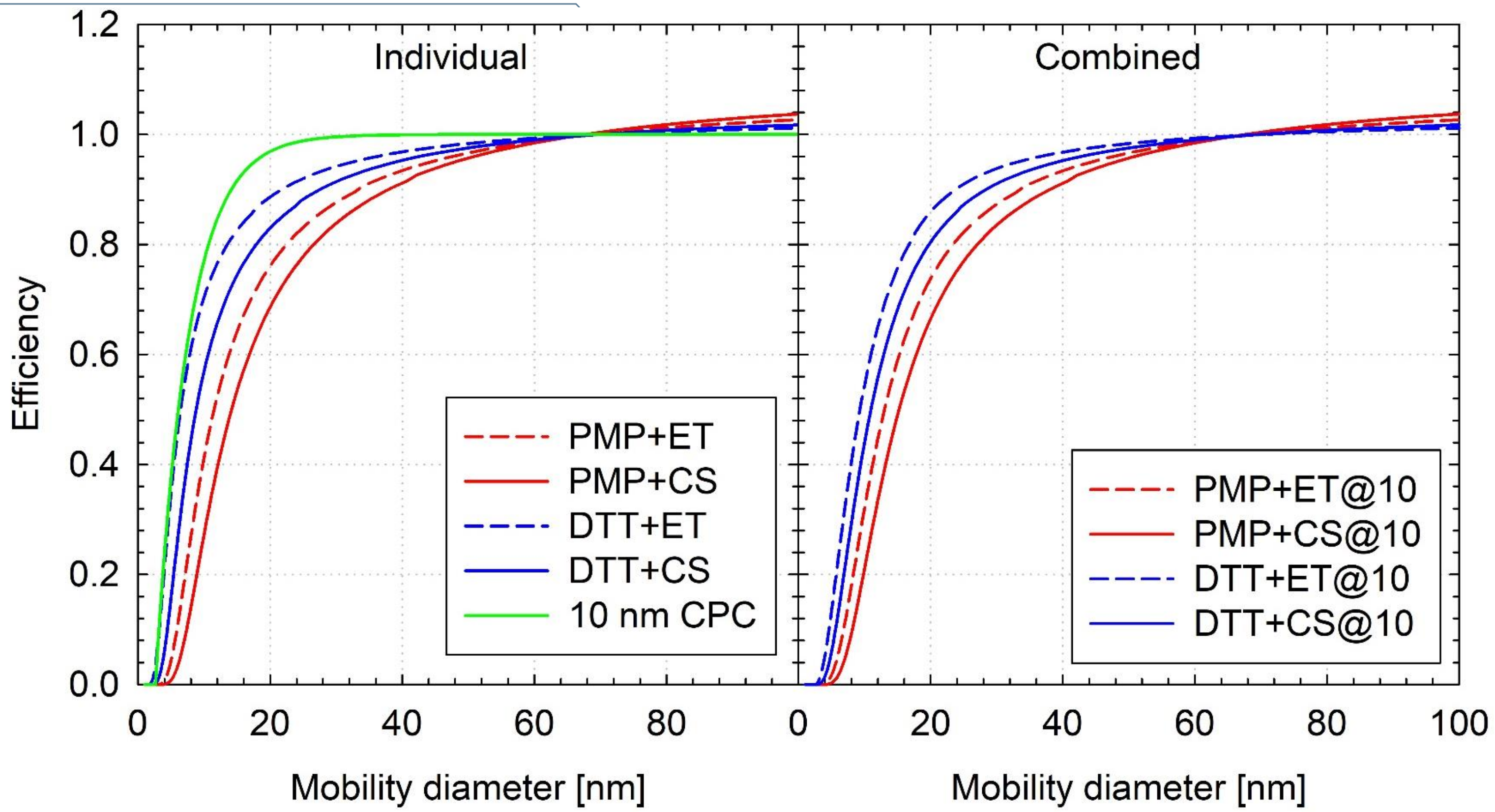
The overall (combined) efficiency of a 23 nm PN system is dominated by the low detection efficiency of the 23 nm CPC (especially for soot particles).

➔ Differences in the sampling losses between systems (i.e. by the use of a CS) have minor effects in overall system efficiency.

➔ Tighter control of CPC counting efficiencies are more useful in improving comparability in the field.

Contribution of individual components on the overall detection efficiency of 10 nm systems

Sampling system penetrations are corrected for the average losses at 30, 50 and 100 nm as defined in the regulation.

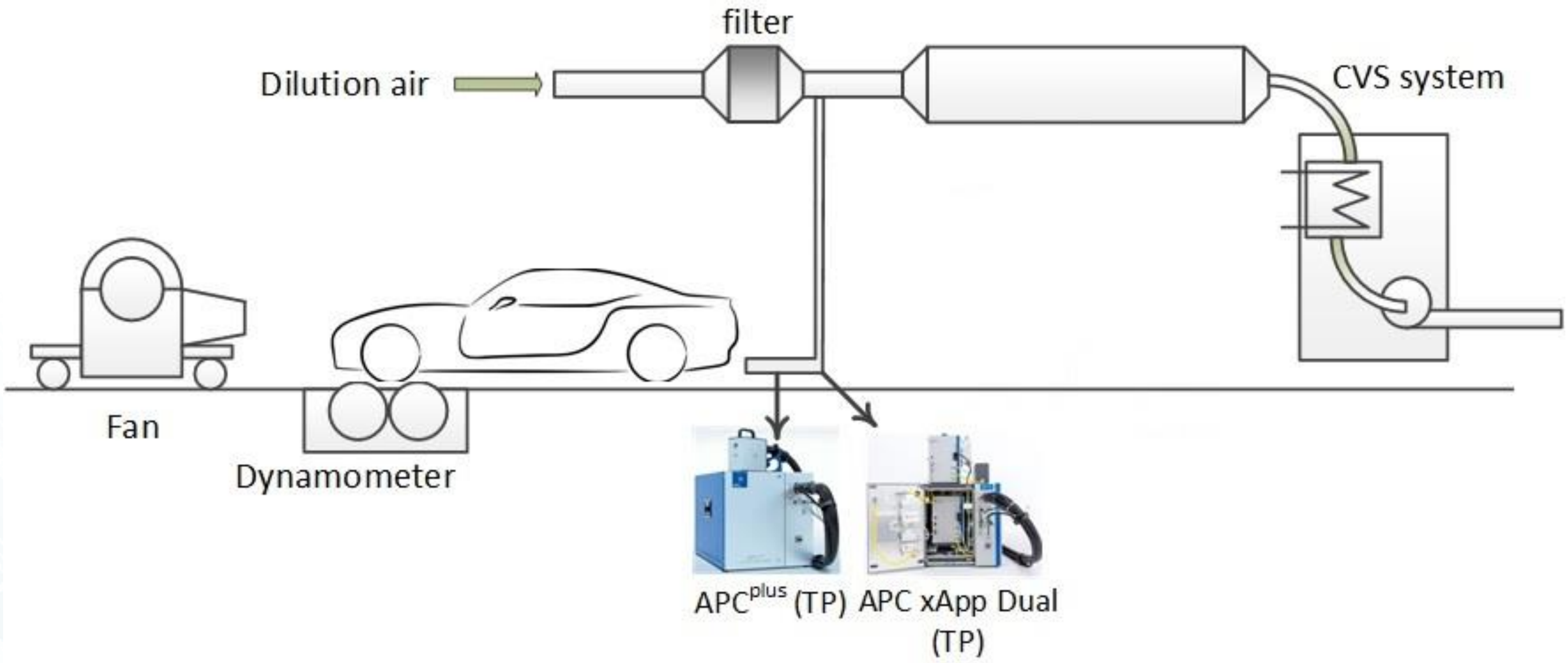


The 10 nm CPC efficiency (50% at ~7nm) is even higher than the penetration of optimized Horizon 2020 sampling systems.

➔ Differences in the losses of different designs will be directly reflected in the comparability of results.

➔ AVL will implement CS in all 10 nm systems to improve comparability of AVL devices (including PEMS) in the field.

Effect of CS on 23 nm measurements
Setup



Parallel measurements with a dual line APC xApp (CS, 10 nm and 23 nm AVL CPCs) and an APC plus (ET, 23 nm AVL CPC) at the tailpipe.

10 tests of G-DI vehicles driven over different cycles (WLTC, NEDC, FTP75, US06).

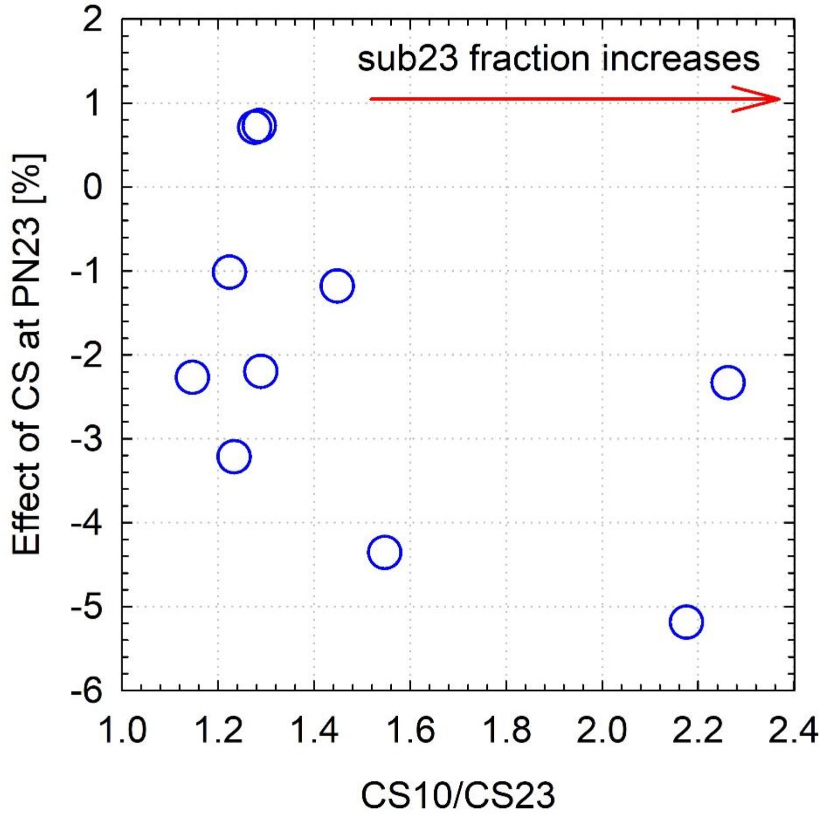
Effect of CS on 23 nm measurements Results

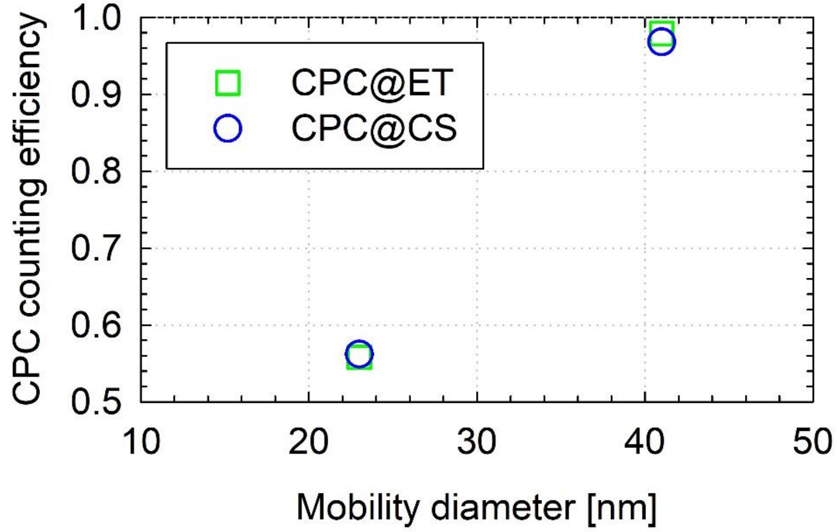
Ratio of 10 to 23 nm concentrations of dual line APC xApp is indicative of the size of emitted particles. The larger the ratio, the smaller the size of the emitted particles:

- Ratios ≤1.3: CMD≥ ~40 nm
  - Effect of CS limited to +1 to -3% (experimental uncertainties of measurements & calibration)
- Ratios ≥1.4: CMD ≤ ~40 nm
  - Effect of CS modestly lower -2 to -5%

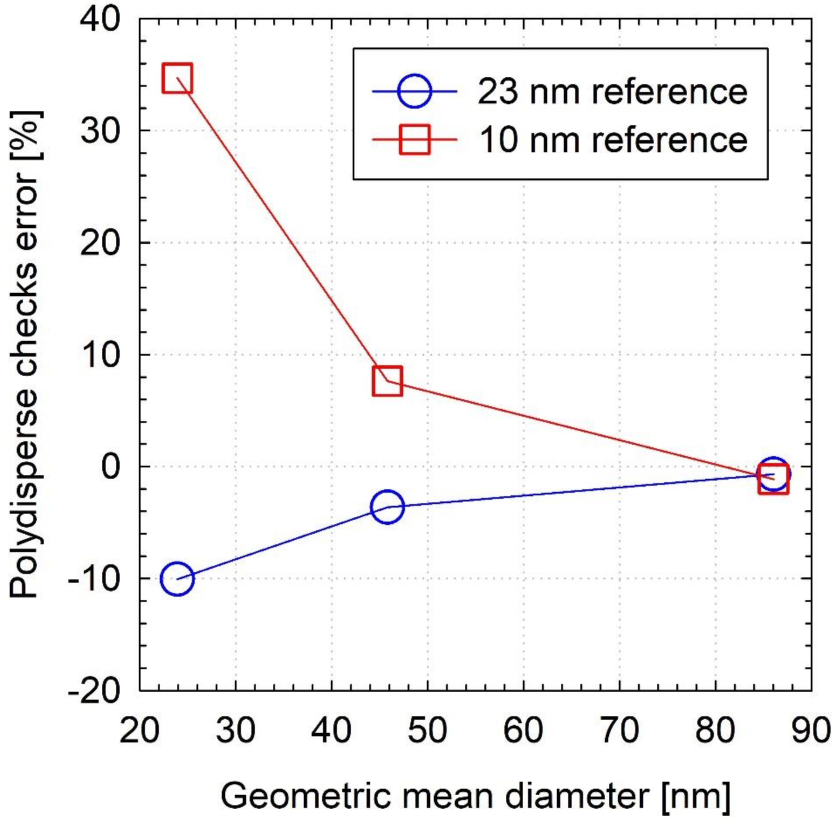
➔ The use of a CS is expected to have minor effect on 23 nm measurements, as it introduces minor additional losses in the measurement size range of 23 nm systems.

Tight control of 23 nm CPC efficiencies during calibration as with AVL 488 CPCs is a prerequisite to accurately quantify such effects!





Polydisperse checks

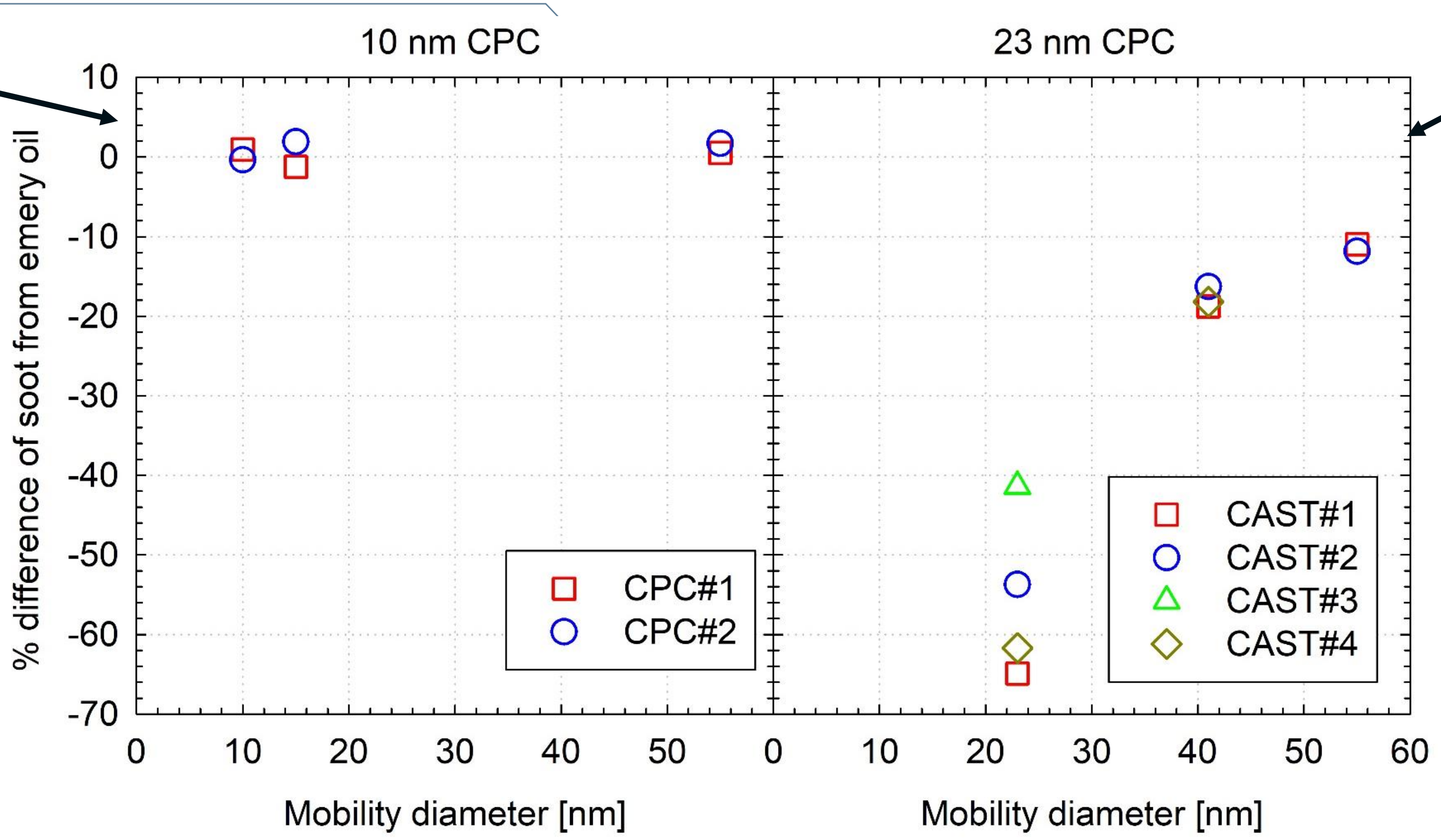


Polydisperse checks using the same 23 nm reference CPC is relatively insensitive of the losses in the system, given the high particle sampling system penetrations over the 23 nm CPC measurement range.

With 10 nm CPCs, this is no longer the case ➔ Polydisperse checks for 10 nm systems are not straightforward and procedure needs to be thoroughly investigated before incorporating such checks in GTR 15.

Calibration material effect

Calibration of two CPCs against an electrometer with emery oil and soot from same CAST settings



Calibration of a single CPC against an electrometer with emery oil and soot from different CAST settings

The differences in the counting efficiencies between soot and emery oil are insignificant for 10 nm CPCs.

Results in good agreement with heterogeneous nucleation theory: Large material effect in 23 nm CPCs is a direct consequence of the very low supersaturations employed compared to their 10 nm counterparts.

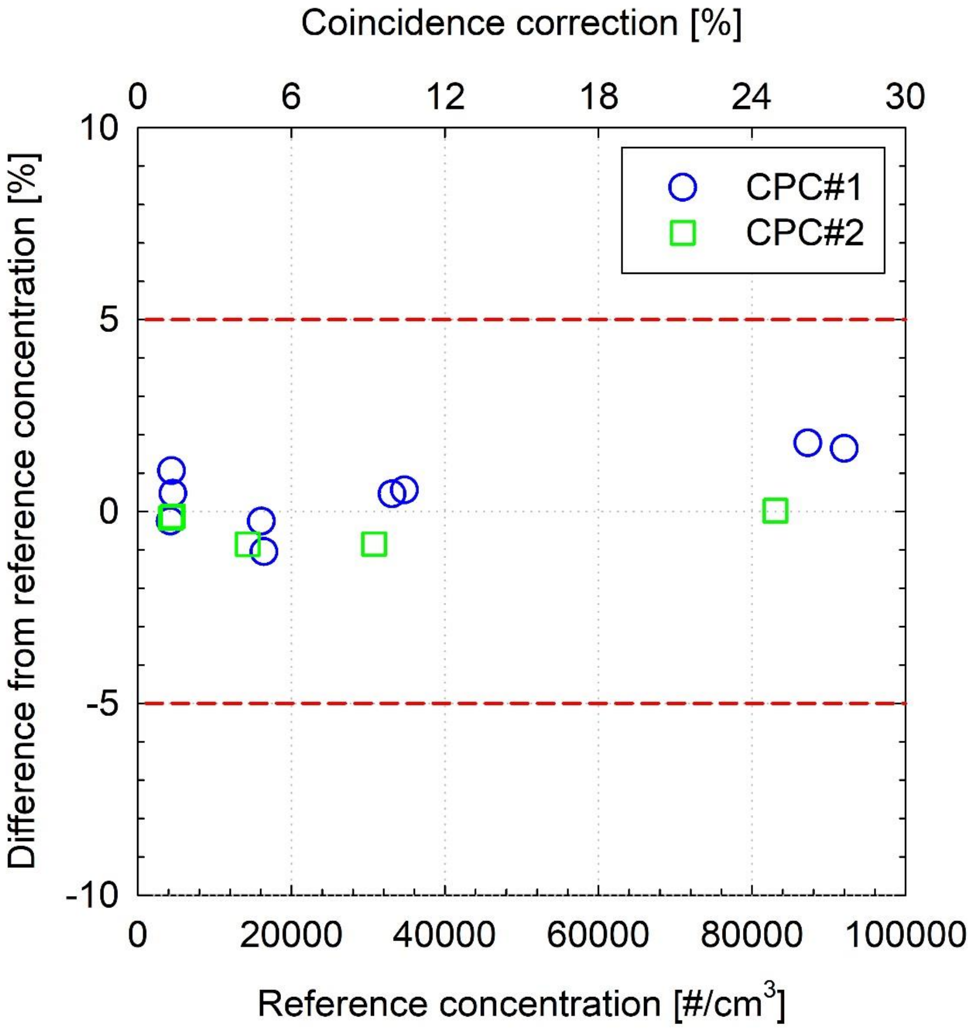
Linearity vs coincidence

The linearity of the AVL CPCs is evaluated against a traceable electrometer in a ISO17025 accredited calibration line, in accordance with ISO 27891.

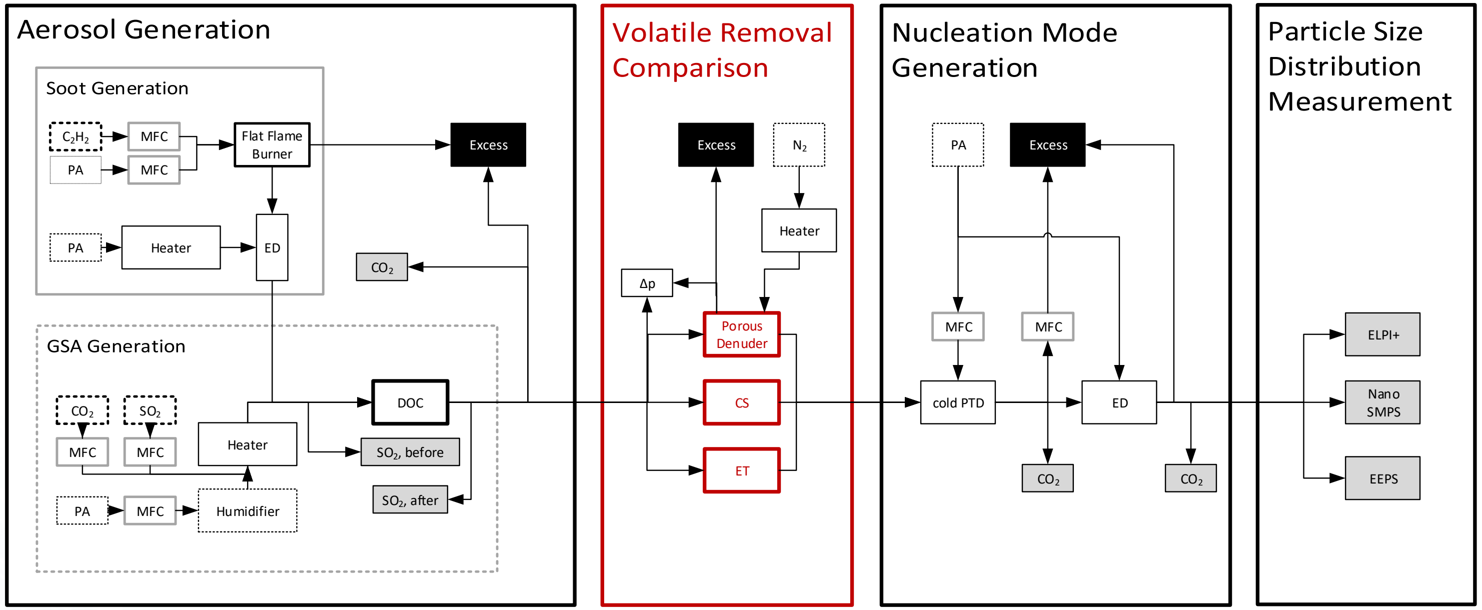
Linearity can be verified over an extended concentration range, mostly limited by the achievable monodisperse concentrations in the calibration setup.

The coincidence correction threshold of 10% is a reminiscence of the very first 23 nm CPC designs requiring post-processing of data using a universal iterative algorithm derived from statistics. Modern (single-count-mode) CPC designs employ advanced algorithms in their firmware, the performance of which is verified during the actual linearity measurements.

➔ No need for extra specifications on coincidence correction



DTT investigations on the performance of CS: #1 Experimental

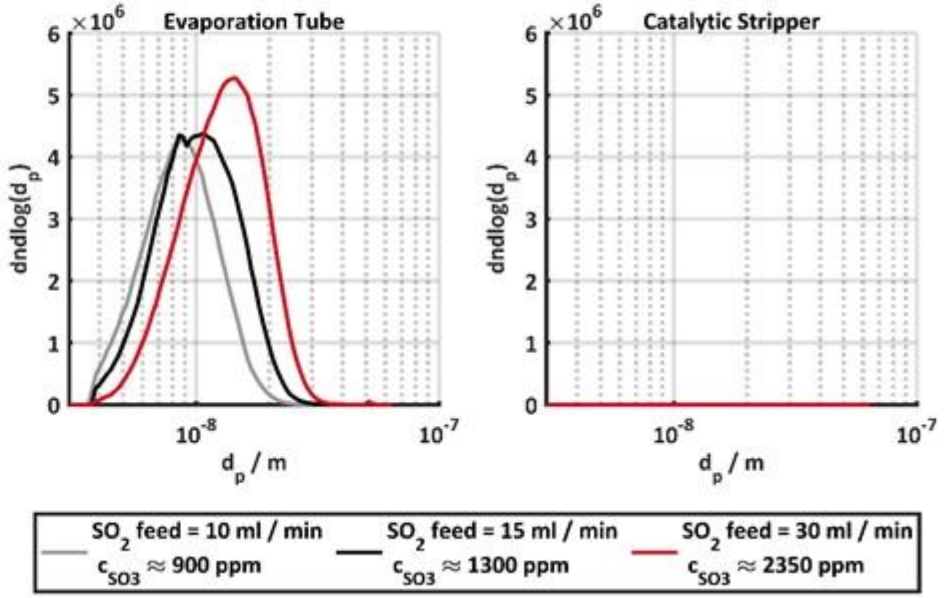


A synthetic exhaust test bench was established within DTT, able of producing controlled amounts of soot and H_2SO_4 concentrations.

Dedicated tests with pure H_2SO_4 were conducted to access the potential offered by CS in suppressing nucleation.

M. Bainschab, A. Bergmann, S. Martikainen, P. Karjalainen, J. Keskinen. A Counter Flow Denuder for Engine Exhaust Conditioning: First Laboratory Experiments. Aerosol Technology Conference, Bilbao, 2018

DTT investigations on the performance of CS: #2 Experimental



AVL's CS was found to completely suppress H_2SO_4 nucleation even at excessive exhaust concentrations of SO_3 (900 to 2350 ppm).

M. Bainschab, A. Bergmann, S. Martikainen, P. Karjalainen, J. Keskinen. A Counter Flow Denuder for Engine Exhaust Conditioning: First Laboratory Experiments. Aerosol Technology Conference, Bilbao, 2018

Conclusions

- The additional losses introduced by the installation of a CS is found to have a minor effect on the 23 nm results ➔ Allowing for CS in 23 nm regulation should not affect comparability with ET-based 23 nm PN systems.

- The introduction of a CS has a strong effect on the performance of 10 nm PN systems ➔ AVL will implement a CS in all 10 nm systems in order to:
  - improve comparability of AVL systems (including PN PEMS) in the field.
  - safeguard against volatile and inorganic artefacts, streamlining the methodology for all possible (including extreme) future applications.

- The established polydisperse validations for 23 nm systems are not directly transferable to 10 nm systems. Dedicated investigations are required if it is to include these checks in the new GTR 15 regulation.

- CPC calibrations verify that the material effect is substantially less critical for 10 nm systems, and that the 10% coincidence correction threshold is introducing unnecessary restrictions in the concentration measurement range of modern single-count-mode CPC designs.

Thank You

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