A Harmonized Method for Monitoring the Number Concentration of Ultrafine Particles in Atmospheric Aerosol

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Introduction and Motivation

Drastically lower particle emissions from the tailpipe due to modern engine technologies and efficient aftertreatment (e.g. DPFs) have led to monitoring **particle number (PN)** in addition to monitoring the mass of particles collected on a filter (PM). The Particulate Measurement Programme **(PMP) introduced PN measurements** with a condensation particle counter (CPC) that resulted in amendments to UNECE Regulation No. 83. Since September 2011, the Euro 5B standard requires a PN limit of 6×10^{11} particles/km for type approval of all new light-duty diesel vehicles, the first PN legislation implemented by the European Union [1]. With the continued input of the VERT association, Switzerland recently pioneered using portable **PN instruments** for periodic control of off-road construction machinery [2].

Lately, it's been realized that **ultrafine particles (UFPs)** can impact human health and our climate, yet contribute very little to the mass of atmospheric particles. In order to assess their impact and provide guidance in future air quality regulations it is therefore necessary to supplement gravimetric air quality measurements with a time resolved **measurement of PN** concentration.

As a first step of harmonizing the continuous measurement of **UFPs in the atmosphere**, the European Committee for Standardization (CEN) drafted Technical Specification CEN/TS 16976 which defines a set of requirements for the Condensation Particle Counter (CPC), its sampling system, the measurement procedure and the reporting of measurement results. Recently, a **new CPC** with a dedicated sampling system, both of which are fully compliant with the proposed **CEN/TS 16976**, have been introduced (model 3772-CEN CPC, TSI Inc., Shoreview, USA).

Requirements of the Technical Specification CEN/TS 16976 (for information only, for any use refer to the original document)

The CEN/TS 16976 "describes a standard method for determining the particle number concentration in ambient air […]. The standard method is based on a Condensation Particle Counter (CPC) operated in the counting mode and an appropriate dilution system for concentrations exceeding the counting mode range." [3]

The CEN/TS 16976:

- contains general information about the properties of the aerosol and the method
- defines performance criteria and test procedures for suitable CPCs (see table 1)
- defines performance criteria and test procedures for the sampling system (see table 2)
- lists requirements for the installation, initial checks and calibrations, and operation of a CPC and sampling system at a monitoring site
- suggests a standardized data reporting format
- describes Quality Assurance and Quality Control procedures

Performance characteristic	Criteria
Actual flow rate	≤ 5 % difference to the nominal flow rate ≤ 2 % difference to the factory-certified flow rate
Concentration response Slope Linearity	 1 ± 0,05 all residuals < 4 % of the measured value
Detection efficiency at low particle size	D_{50} = 7 nm ± 0,7 nm D_{90} < 14 nm
Detection efficiency (at intermediate particle sizes)	> 95 % at (50 ± 10) nm

Table 1: Excerpt from [3] - CPC performance criteria

Performance characteristic	Criterion
Diffusion losses for smallest relevant particle size of 7 nm	< 30 %
Relative humidity of primary flow at CPC inlet	< 40 %, accuracy ±3 %

Table 2: Excerpt from [3] - sampling system performance criteria

The 3772-CEN CPC

The Model 3772-CEN Condensation Particle Counter (CPC) is fully compliant to the new CEN Technical Specification CEN/TS 16976.

Enhancement	Design Feature
Concentration Accuracy	Pulse height analyzer to monitor wick health, supersaturation state, and instrument status.
	Low concentration: full flow measurement with improved statistics
	High concentration: optimized coincidence and dead time correction
	Inlet nozzle optimization for improved counting efficiency
Flow Rate Stability	Critical orifice air flow scheme (no need for flow control orifice)
Reliable Operation	Inlet pressure monitor to prevent flooding
	Data logging to CEN data record
	Data backup on SD/MMC flash memory card
	Easy to integrate into centralized data acquisition systems
	Automated Butanol filling
Precision Measurements	Enhanced zero count stability
	Real time clock
On-board Instrument Diagnostics	Nozzle pressure transducer to monitor nozzle health
	Laser health monitor
	Extended instrument status information

Table 3: 3772-CEN CPC Design Features & Improvements

The Sampling System

The Sampling System is designed for low particle losses with flexibility in its use. It consists of a $PM_{2.5}$ sampling inlet to remove large particles, a single tube Nafion® dryer to control humidity and a built-in dilution of 1:5 (other dilution ratios are offered upon request).

Prior to the inlet of the CPC the temperature and humidity are measured and reported to the CPC.

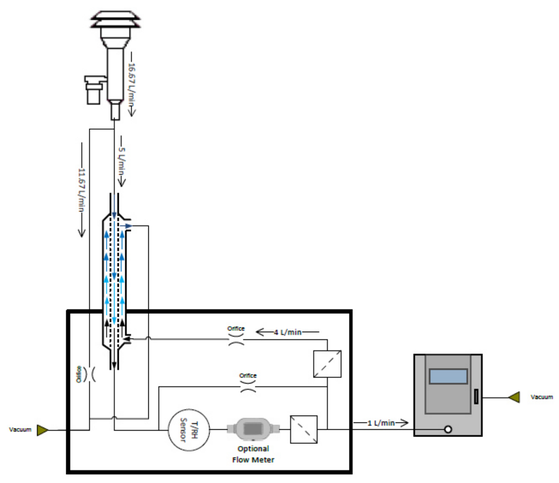

Figure 1: Schematic of the Sampling System

Characterization & Calibration

The World Calibration Centre for Aerosol Physics, Leibniz Institute for Tropospheric Research (TROPOS) has calibrated and characterized the first CPCs for counting efficiency.

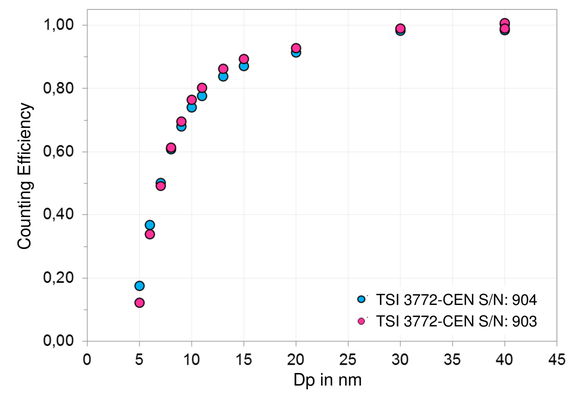

Figure 2:
Counting efficiency for silver particles that are generated with the evaporation/ condensation method

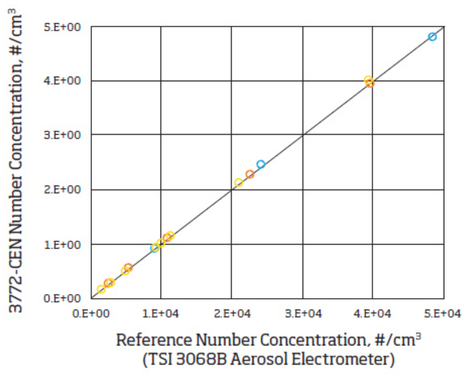

Figure 3:
Linearity: Data points show data for 4 units, black line shows y=x

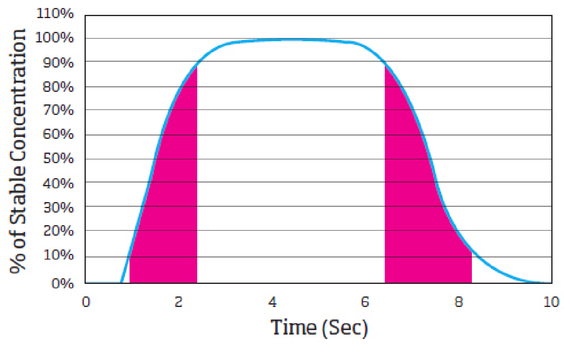

Figure 4:
Response time: Shown are t_{rise} < 2 s and t_{fall} < 2 s for the 3772-CEN CPC

Conclusions and Summary

The CEN/TS 16976 harmonizes the continuous measurement of UFPs in the atmosphere by defining a set of requirements for the CPC, its sampling system, the measurement procedure and the reporting of measurement results. The standardized data gathered through atmospheric monitoring following a harmonized method will facilitate global comparison of UFP data.

Recently, TSI released a new CEN/TS 16976 compliant CPC with a dedicated sampling system which is calibrated and characterized by TROPOS. The model 3772-CEN CPC brings the same technology and accuracy to atmospheric monitoring that the EECPCs used in type approval testing according to Euro 5b/6 legislations rely on. Atmospheric researchers can now expect the same accuracy and very tight tolerances.

References

[1] Bischof, O.F. (2015). Recent Developments in the Measurement of Low Particulate Emissions from Mobile Sources. *Emiss. Control Sci. Technol.* Vol. 1, (2).
[2] SR 941.242. Ordinance of the FDJP on Exhaust Gas Analysers (VAMV), 19th March 2006 (latest changes effective 1st March 2014).
[3] CEN/TS 16976. Ambient air - Determination of the particle number concentration of atmospheric aerosol, release in summer 2016