DOI 10.5162/SMSI2023/P20

A Method for In-Field Calibration for Periodical Technical Inspections Particle Counter Devices

Helmut Krasa[1], Martin Kupper[1], Mario A. Schriefl[1,2], Alexander Bergmann[1]
[1] Institute of Electrical Measurement and Sensor Systems, Graz University of Technology, Graz, Austria,
[2] Emission Measurement Department, AVL DiTEST GmbH, Graz, Austria
helmut.krasa@tugraz.at

Summary:
The introduction of particle number (PN) emission limits in periodical technical inspection for passenger cars leads to the need of PN measurements for any individual car. Besides the need for measurement devices, a fast and simple PN calibration method to allow for high-throughput calibration is key. In this work we present such a calibration method to evaluate the linearity and the plateau counting efficiency region of a PN counter is on-site.

Keywords: Particles, Number Concentration, Vehicle Emission, Periodical Technical Inspections

Introduction

The introduction of particle number (PN) limits for vehicle homologation in the European Union led to a decrease in particle emission levels in urban environment [1]. A sample survey by Burtscher et al showed that 10% of the highest emitting vehicles are responsible for 85% of the PN emission [2].

In order to identify those high emitters, Germany introduces PN emission limits for Euro 6 diesel vehicles as part of the periodic technical inspection (PTI) starting in 2023. This will increase the number of PN counters in use manifold. Calibration of PN counters for usage in homologation measurements must be performed according to ISO 27891, which is of high effort and requires an appropriately equipped lab. Additional efforts are added by ISO 17025 to ensure traceability including a reference counter, mass flow controllers and a differential mobility analyzer to select monodisperse particles as well as a rigid procedure.

Since around 35,000 PN counters will have to be calibrated for PTI per year in Germany alone from 2023 onwards, and the requirements for PTI devices are less stringent than for approval devices, a faster and simpler calibration procedure is needed.

PN counter calibration addresses two quantities. First, the counting efficiency (CE), which is defined as the ratio of number concentration of particles counted divided by a reference number concentration. The CE must be calibrated in the transition regime for particles smaller than 50 nm and at the efficiency plateau for bigger sizes. A typical PN counter CE curve with calibration limits for PTI devices is shown in Fig. 1. As can be seen, the CE is heavily impacted by the particles' chemical composition. Secondly, the counter must show a linear response over the whole particle concentration range.

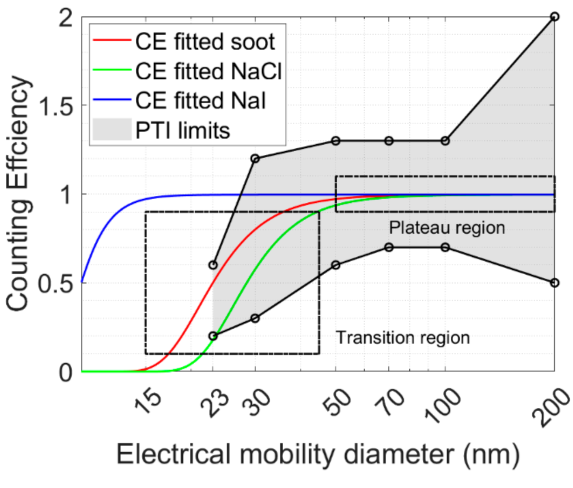

Fig. 1: Graph of fitted CE curves for three particle types of a PN counter curve and the required limits for calibration

In this work, we present a method that allows for in-field calibration of the linearity and plateau efficiency.

Methods and Results

Particles were generated with an atomizer that creates droplets from aqueous salt solutions. The droplets are then dried, leaving airborne salt particles. The setup is shown in Fig 2. We used NaI, which shows CEs bigger than 50% down to

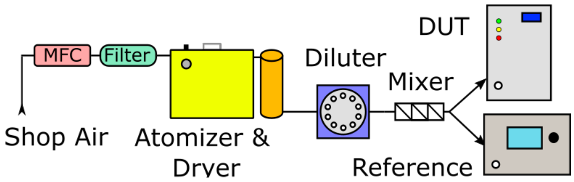

Fig. 2: Measurement Setup to evaluate the plateau CE, consisting of a particle source, a diluter, a mixer, a reference counter and the device under test (DUT).

18 nm, unlike the commonly used NaCl (Fig 1) [3]. The mean particle size changes with the salt concentration. Compared to other methods of particle generation, the atomizer has reduced tuning options, but is easy to use, portable and only requires pressurized air and an appropriate salt solution. Two size distributions for different salt concentrations of NaI are shown in Fig. 3. NaI shows a high CE at small sizes and the particle size distribution shows low concentrations below 15 nm. This means, that all particles generated by the atomizer are counted. For NaI, it is therefore possible to perform calibration without using monodisperse particles. Thus, the use of a differential mobility analyzer can be avoided, which makes the setup suitable for field use.

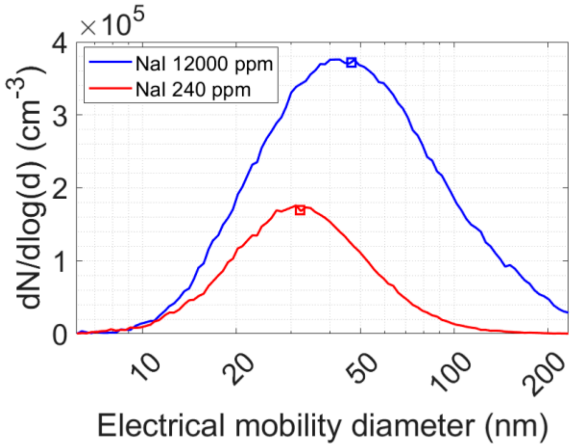

Fig. 3. Particle size distribution and their geometric mean diameter of NaI for two concentrations. Mean diameters were 46.8 and 32.1 nm.

Results

At first, we evaluated the CE for monodisperse particles at sizes in the plateau region. The respective data can be seen in Table 1.

Table. 1: CE of monodisperse NaI particles

Size / nm	Counts Refence / cm^{-3}	Counts DUT / cm^{-3}	CE
30	1170	1250	1.068
50	1950	2100	1.077
75	2520	2750	1.091
100	2250	2450	1.088
Average			1.085

The CE was then evaluated for polydisperse NaI (high concentration). The PN concentrations were between 80 cm^{-3} and 30 000 cm^{-3}. Typically, linear regressions are used, however the fitted CE is then primarily determined by the value at the highest concentration [4]. Instead, we used the averaged CE and fitted it for the polydisperse measurement, as can be seen in Fig 4. Good linearity was observed over the whole concentration range. The mean CE of 1.079 agrees within 1 % with the monodisperse measurement of 1.086.

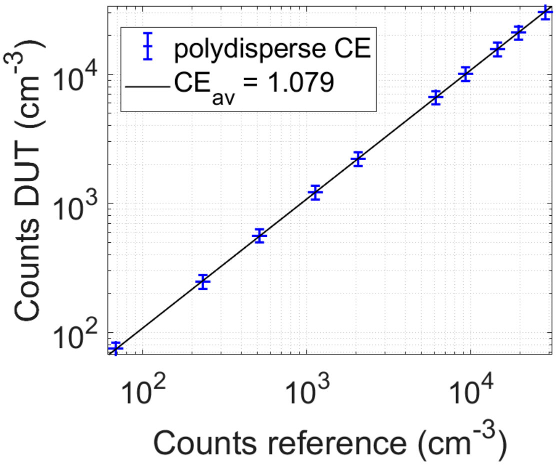

Fig. 4: Linearity test for polydisperse NaI between 80 cm^{-3} and 30 000 cm^{-3}.

Conclusion and Outlook

The plateau efficiency of a PN counter was successfully calibrated with polydisperse, atomized NaI particles. This method does not need a differential mobility analyzer and allows for in-field calibration, only requiring a compact atomizer, pressurized air and a reference counter. A portable calibration method for the CE of the transition regime using polystyrene latex is subject of current investigations.

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