The Traceable Calibration of Condensation Particle Counters

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Why calibrate CPCs?

- Condensation particle counters (CPCs) have been used to measure number concentration of ultrafine particles for almost 30 years
  - As part of scanning mobility particle sizer (SMPS™) to measure size distributions as well
- Currently new regulations involving particle number concentration measurements are discussed
- Hence, calibration of CPCs using a traceable method to ensure proper performance is required
  - Method to calibrate smallest particle size detection limit, counting efficiency & concentration linearity
Calibration: The set of operations that establish, under specific conditions, the relationship between values for quantities indicated by a measuring instrument or measuring system, or values represented by a material measure or a reference material, and the corresponding values realized by standards.

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The calibration method at TSI follows the well-known ‘primary absolute calibration’ method first described by leading aerosol scientists B. Liu and D. Pui in 1974

- Electrospray AG generates (emery oil) particles
- DMA selects singly-charged, monodisperse particles of known size
- Monodisperse aerosol mixes with filtered air & splits equally into aerosol electrometer and CPC
- Counting efficiency: ratio CPC / electrometer readings
This presentation discusses calibration results for standard TSI model 3010 and 3010D (PMP) CPCs.

- Smallest particle size detection limit & Counting efficiency
- Concentration linearity
- CPC intercomparison
Traceability of the CPC calibration method depends on:

- The ability of generating singly-charged, monodisperse particles of known size

- The ability of measuring particle concentration accurately using a reference aerosol detector
**Monodispersity of Particles**

**Step 1:** Particles generated by electrospray (22 nm, GSD = 1.46)

**Step 2:** Particles generated by electrospray and selected by DMA (22 nm, GSD = 1.04)

Electrospray-generated, DMA-selected particles:
- 50 nm: GSD = 1.04
- 90 nm: GSD = 1.11
In a cylindrical DMA, $Z_p$ of selected particles is

$$Z_p = \frac{[q_t - 1/2(q_p + q_m)]\ln(r_2/r_1)}{2\pi VL}$$

- Flow rates ($q_t=q_s+q_p$) – NIST traceable flow meters
  - Sheath flow rate ($q_s$)
  - Polydisperse/Monodisperse aerosol flow rate ($q_p = q_m$)
- Geometric parameters – NIST traceable bore gage, micrometer, and caliper
  - $r_1/r_2 =$ inner / outer electrode radius
  - $L =$ characteristic length between aerosol inlet/outlet slits
- Voltage on center electrode ($V$) – calibrated with NIST traceable kilovolt divider
Aerosol Electrometer

\[ N = \frac{V}{e \cdot R \cdot n_p \cdot q_e} \]

**where:**
- \( N \) = particle number concentration
- \( V \) = electrometer voltage reading (IR)
- \( e \) = unit charge, \( 1.602 \times 10^{-19} \) C
- \( R \) = resistance of resistor
- \( n_p \) = number of charges per particle
- \( q_e \) = air flow rate
Unit charge \((e)\) – is a constant \((1.602 \times 10^{-19} \text{ C})\)
Resistor \((R)\) – 1% precision, measured by manufacturer using NIST traceable standard
Particle charge \((n_p)\) – verified to be unity \((1.0)\) by SMPS
Flow rate \((q_e)\) – NIST traceable flow meter
Inlet tubing to the Faraday cage must be kept as short as possible or losses must be quantified and corrected.
Smallest Particle Size & Counting Efficiency

- Depending on CPC model, 10 – 14 particle sizes below 100 nm used for counting efficiency curve
- Particle concentration < 10^4 P/cm³
- CPCs 3010, 3010D (or other models) can be tested simultaneously
  - Model 3776 is tested one by one due to low concentration at their smallest particle sizes
- To eliminate need for diffusion loss correction
  - Equal tube lengths from flow splitter to electrometer & CPCs
  - Equal flow rates for electrometer & CPCs
- CPC concentrations corrected for coincidence
Results: Counting Efficiency of 3010

<table>
<thead>
<tr>
<th>Size Range</th>
<th>SN2311_S</th>
<th>SN2454_S</th>
<th>SN2460_S</th>
<th>SN70419349_S</th>
<th>SN70419353_S</th>
<th>Size Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>D10, nm</td>
<td>7.2</td>
<td>6.5</td>
<td>6.4</td>
<td>6.9</td>
<td>6.5</td>
<td>6.8 ± 0.4</td>
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<tr>
<td>D25, nm</td>
<td>8.3</td>
<td>7.6</td>
<td>7.5</td>
<td>8.0</td>
<td>7.4</td>
<td>7.9 ± 0.5</td>
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<tr>
<td>D50, nm</td>
<td>9.9</td>
<td>9.1</td>
<td>9.1</td>
<td>9.7</td>
<td>8.9</td>
<td>9.4 ± 0.5</td>
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<td>D75, nm</td>
<td>11.9</td>
<td>11.0</td>
<td>11.0</td>
<td>11.7</td>
<td>11.1</td>
<td>11.4 ± 0.4</td>
</tr>
<tr>
<td>D90, nm</td>
<td>14.0</td>
<td>13.0</td>
<td>13.0</td>
<td>13.8</td>
<td>13.6</td>
<td>13.5 ± 0.5</td>
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</tbody>
</table>
Results: Counting Efficiency of 3010D

<table>
<thead>
<tr>
<th>Particle Size, nm</th>
<th>SN2454_M</th>
<th>SN2460_M</th>
<th>SN70419351_M</th>
<th>SN70419354_M</th>
<th>SN70419352_M</th>
<th>Size Range</th>
<th>PMP Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>D10, nm</td>
<td>15.9</td>
<td>16.2</td>
<td>15.8</td>
<td>16.4</td>
<td>16.5</td>
<td>16.1 ± 0.4</td>
<td>16 ± 1</td>
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<tr>
<td>D25, nm</td>
<td>17.9</td>
<td>18.2</td>
<td>17.9</td>
<td>18.5</td>
<td>18.4</td>
<td>18.2 ± 0.3</td>
<td>18 ± 2</td>
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<tr>
<td>D50, nm</td>
<td>21.3</td>
<td>21.6</td>
<td>21.5</td>
<td>22.1</td>
<td>21.9</td>
<td>21.7 ± 0.4</td>
<td>23 ± 3</td>
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<tr>
<td>D90, nm</td>
<td>34.9</td>
<td>35.3</td>
<td>33.4</td>
<td>33.9</td>
<td>34.8</td>
<td>34.3 ± 1.0</td>
<td>37 ± 4</td>
</tr>
</tbody>
</table>
Counting Efficiency Results for Twelve 3010D Production CPCs.
**Concentration Linearity**

Setup for concentration linearity response \(^4\)
- 50 nm particles chosen for \(~100\%\) counting efficiency for CPC
- Six to ten concentrations levels, depending on CPC model
  - Higher concentrations reduced by dilution bridge
- Equally spaced from 0 - \(10^4\) P/cm\(^3\) (CPC 3010) and 2,000 to 300,000 P/cm\(^3\) (UCPC 3776) respectively
- Reference instrument
  - Aerosol Electrometer 3068A (for 3776 only for validation)
    - From April 2006 new aerosol electrometer model 3068B

Linearity Response of 3010 & 3010D

Slope = 0.953 to 0.973
R² > 0.9988
Linearity Response of Twelve 3010D Production CPCs.
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