Dekati® High Temperature ELPI+™

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Hot particle sample
### Sample conditioning

<table>
<thead>
<tr>
<th>Sampling dynamics</th>
<th>Effect of dilution parameters</th>
<th>Particle Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nucleation</td>
<td>Temperature</td>
<td>Inertial</td>
</tr>
<tr>
<td>Condensation</td>
<td>Residence time</td>
<td>Gravitational</td>
</tr>
<tr>
<td>Evaporation</td>
<td>Humidity</td>
<td>Turbulent</td>
</tr>
<tr>
<td>Coagulation</td>
<td>Dilution ratio</td>
<td>Diffusion</td>
</tr>
</tbody>
</table>

- Thermophoretic
- Electrophoretic
ELPI+™

- Real-time particle size distribution
- 6 nm – 10 µm
- Operation
  - Charger: particle charging
  - Impactor: particle size classification
  - Electrometers: electrical detection of charged particles
High Temperature ELPI+™

- Same operating principle as ELPI+™
- Charger+Impactor moved to external heating unit, max 180 °C
- Allows hot aerosol size and charge distribution measurement in real-time
High Temperature ELPI+™

- 6 nm – 10 µm
- 10 lpm
- 10/1 Hz
- Max 180 °C
- Heater power 500 W
- Max. 1000/500 W for External heater (230V/110V)
- Temperature measurements
  - Sample inlet
  - Impactor outlet
  - Heater
- Pre-set calibration values 60, 120 and 180 °C
  - Calculation sheet provided for other temperatures
HT-ELPI+™ Collection Foils

- Aluminium foils
- Greased aluminium foils, max 100 °C
- Apiezon-L grease, max 100 °C
  - Same for Dekati® Collection Substrate Spray
- Apiezon-H grease, max 200 °C
- Polycarbonate collection foils, max 140 °C
- HT-ELPI+™ not yet compatible with sintered collection plates
Effect of Temperature on ELPI+™ Calibration

- Impactor cutpoint calculation is based on pressure measurement and known (calibrated) Stokes numbers

- Temperature changes gas flow rate, jet velocity in the impactor nozzles, gas viscosity and mean free path

- Charger efficiency assumed to remain constant

<table>
<thead>
<tr>
<th>Stage</th>
<th>21 °C D50, μm</th>
<th>100 °C D50, μm</th>
<th>180 °C D50, μm</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.016</td>
<td>0.013</td>
<td>0.011</td>
</tr>
<tr>
<td>3</td>
<td>0.028</td>
<td>0.024</td>
<td>0.022</td>
</tr>
<tr>
<td>4</td>
<td>0.056</td>
<td>0.044</td>
<td>0.037</td>
</tr>
<tr>
<td>5</td>
<td>0.094</td>
<td>0.080</td>
<td>0.068</td>
</tr>
<tr>
<td>6</td>
<td>0.155</td>
<td>0.138</td>
<td>0.123</td>
</tr>
<tr>
<td>7</td>
<td>0.262</td>
<td>0.242</td>
<td>0.224</td>
</tr>
<tr>
<td>8</td>
<td>0.382</td>
<td>0.371</td>
<td>0.355</td>
</tr>
<tr>
<td>9</td>
<td>0.613</td>
<td>0.599</td>
<td>0.587</td>
</tr>
<tr>
<td>10</td>
<td>0.948</td>
<td>0.955</td>
<td>0.950</td>
</tr>
<tr>
<td>11</td>
<td>1.60</td>
<td>1.66</td>
<td>1.67</td>
</tr>
<tr>
<td>12</td>
<td>2.39</td>
<td>2.53</td>
<td>2.55</td>
</tr>
<tr>
<td>13</td>
<td>3.99</td>
<td>3.75</td>
<td>3.80</td>
</tr>
<tr>
<td>14</td>
<td>6.68</td>
<td>5.52</td>
<td>5.60</td>
</tr>
<tr>
<td>15</td>
<td>9.91</td>
<td>10.18</td>
<td>10.37</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flow [lpm]</th>
<th>21 °C</th>
<th>100 °C</th>
<th>180 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9.92</td>
<td>11.17</td>
<td>12.31</td>
</tr>
</tbody>
</table>
Impactor internal temperatures during heating

Graph showing temperature changes over time for various points labeled T1 to T8.
Test engine

- MY 1999, 2 liter MB W124 Gasoline engine, converted for natural gas use, VTT engine dynamometer
- Exhaust gas synthesizer to mimic large bore natural gas engine exhaust composition
- Tests at 11-22 kW
Natural gas engine test bench

Flow control → Exhaust out 80 kg/h

- NOx analyzer
- NOx sensor
- FTIR
- Pump / flow control
- Mass flow measurement
- Urea injection
- FTIR
- THC / CH4 analyzer
- CO2, CO, O2, NOx analyzer
- HT-ELPI+
- Ejector diluter
- Diluter
- Nano-SMPS DMA 3085 UCPC 3025

GAS INJECTION
- Methane
- Propane
- Ethane
- Ethene
- Mass flow controller

Exhaust in 80 kg/h

- T ≈ 400 - 445 °C
- SCR

Heating unit for exhaust gas

- T ≈ 400 °C
- Particle mass measurement (ISO-8178)
- CO2, CO, O2, NOx analyzer

- NOx sensor
- T ≈ 420 °C
- DR ≈ 6 * 4

Mass flow controller

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HT-ELPI+/™ results: size distribution

- Number distribution:
  - Highly charged particles
  - 30,000 #/cm³
  - (7,000 #/cm³ for >10 nm)

- Volume distribution:
  - 0.0078 mg/m³
Comparison to diluted measurements

### Particle size distributions

<table>
<thead>
<tr>
<th>dN/LogDp [#/cm³]</th>
<th>Particle size [μm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1E+8</td>
<td>1.000</td>
</tr>
<tr>
<td>1E+7</td>
<td>0.010</td>
</tr>
<tr>
<td>1E+6</td>
<td>0.001</td>
</tr>
<tr>
<td>1E+5</td>
<td></td>
</tr>
<tr>
<td>1E+4</td>
<td></td>
</tr>
<tr>
<td>1E+3</td>
<td></td>
</tr>
<tr>
<td>1E+2</td>
<td></td>
</tr>
<tr>
<td>1E+1</td>
<td></td>
</tr>
<tr>
<td>1E+0</td>
<td></td>
</tr>
</tbody>
</table>

#### Number [#/cm³]

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>HT-ELPI+ &gt;10 nm</td>
<td>3.0e+4</td>
</tr>
<tr>
<td>HT-ELPI+</td>
<td>7.0e+3</td>
</tr>
<tr>
<td>ISO 8178 (AVL SS)</td>
<td>7000</td>
</tr>
</tbody>
</table>

#### Mass [mg/m³]

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>HT-ELPI+ (dens=1)</td>
<td>0.0078</td>
</tr>
<tr>
<td>SMPS Without TD</td>
<td>3.5e7</td>
</tr>
<tr>
<td>SMPS With TD</td>
<td>2.7e6</td>
</tr>
</tbody>
</table>

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Result: Charge levels

3093 rpm, 33 Nm, 11 kW, Ethene + Propane injection
HT-ELPI+ Electrometer currents

Current [fA]

<10 nm
15 nm
29 nm
50 nm

0.078 mg/m³
HT-ELPI+™

- Same advantages as with ELPI+™
- Direct measurement of sample in source conditions
  - High Temperature measurement, up to 180 °C
  - No dilution required
    - No uncertainties or particle transformations caused by dilution
    - Improved sensitivity
    - Low concentration measurements
- Diluted measurements may provide different results
- Things to consider
  - Sample concentration
  - Sample temperature
  - Heating time (stainless steel impactor)
  - Collection foil material (max temperature)
  - Connection to the pump (max temperature)
High Temperature ELPI+™: Applications

• Engine emissions
  – Tailpipe particle characterization
  – Solid particle research
  – OBD sensor studies at OBD conditions
  – Tailpipe particle charging studies
  – Particle formation studies
  – PEMS

• Stationary source emission measurements
  – Emission characterization
  – Direct measurements from wet stacks
  – After treatment device characterization studies
  – Low concentration measurements
  – Particle formation studies
  – Particle charging studies
Excellence in Particle Measurements

Questions?