Stainless-steel diffusion screens in size-resolved ultrafine particle concentration measurements with a CPC validation and performance evaluation

IX Convegno Nazionale sul Particolato Atmosferico
Knowledge about size-resolved critical sub-100 nm range of ultrafine particles (UFP) is still sparse, especially in urban areas.

Measurements of Nanoparticles in the sub-100 nm size range require different techniques

- Condensation particle counters (CPC)
- Differential Mobility Analyzer (DMA)
- Mobility particle size spectrometers (a combination of DMA and CPC) or …

- Stainless-steel diffusion screens (principle of diffusion batteries)

The aim is to characterize size-dependent penetration efficiencies of one/several stainless-steel diffusion screens and to compare particle concentrations measured by SMPS and CPC using different sets of diffusion screens.
The theoretical background

The diffusion screens (DS) consist of a set of stainless-steel meshes which are placed in the sample flow upstream the CPC.

The penetration efficiency $P$ of a number of $n$ stacked stainless-steel diffusion screens is...

$$P = \exp(-3.5 \cdot n \cdot \left( \frac{2r_S U_0}{D_c} \right)^{-2/3})$$

$r_S$ radius of screen wires
$U_0$ flow velocity
$D_c = \frac{k T C_c}{3\pi \mu D_p}$ particle diffusion coefficient
$D_p$ particle diameter

The variation of $P$ with particle size $D_p$ is the theoretical basis for the size-dependent removal of particles from an aerosol by a diffusion screen.
The aerosol expands in an entrance cone, then it passes through a filter holder (25 mm) and the screens. The effective cross-sectional area of the undisturbed aerosol flow through the DS is the inside diameter of the disk (19 mm).

For experimental validation, a flow reactor is used to generate a particle population with a geometric mean diameter of 30-35 nm from ozonolysis of limonene. Particle number size distributions are measured sequentially with and without diffusion screens (six DS) with …

- Grimm SMPS from 8-272 nm (38 size bins)
- Grimm CPC model 5.401 for the total particle number concentration
After averaging 3 particle number size distribution scans...

Experimental penetration efficiency $P_D$: is the ratio of measured particle number size distributions with and without DS:

$$P_D = \frac{N_{D,\text{with screens}}}{N_{D,\text{without screens}}}$$  \hspace{1cm} (2)

$P_{D,\text{exp}} \text{ VS } P_{D,\text{theor}}$ good agreement for up to 5 DS!

$P_{D,\text{exp}} < P_{D,\text{theor}}$ with 6 DS

Theoretical calculation: $r_S = 12.5 \mu m$, volumetric flow rate through the filter holder $Q = 0.26 l \text{ min}^{-1}$, $U_0 = 0.152 \text{ m s}^{-1}$.
Results

The D50 cutoff diameters for different numbers (1-5) of screens.

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<tr>
<th># screens</th>
<th>D50% [nm]</th>
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<tbody>
<tr>
<td>0</td>
<td>5</td>
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<tr>
<td>1</td>
<td>12.6</td>
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<tr>
<td>2</td>
<td>21.5</td>
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<tr>
<td>3</td>
<td>29.4</td>
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Experimental concentration ratios measured after passing through different $n$ of diffusions screens VS theoretical concentration ratios.

- 1-5 screens vs. 0 screens
- 2-5 screens vs. 1 screen
- 2-5 screens vs. 2 screens
- 4-5 screens vs. 3 screens

For larger numbers of screens, $P_{D,\text{exp}} < P_{D,\text{theor}}$
A first intercomparison of CPC/DS setup and a SMPS: six days of ambient measurements of the particle number concentration in the diameter range 5 - 12.6 nm.
A quantitative comparison of CPC/DS measurement VS SMPS.
An experimental setup for the real-time measurement of ultrafine aerosol size fractions was characterized.

The setup consists of a condensation particle counter (CPC) and a sampling line switching between several diffusion screens (DS).

- Experimental penetration efficiencies in good agreement with theoretical penetration curves up to five DS.
- Deviations of experimental and theoretical values increase with number of DS; potentially due to disturbed flow conditions, changes of effective flow velocities, and/or changes of effective cross-sectional diameter of screens.
- First comparison between CPC/DS setup and SMPS of ambient aerosol shows promising agreement.

The CPC-DS setup represents a simple and robust tool for measuring ultrafine particle size fractions without charging.
Thanks for your attention!