The Practical Aspects of Nanoparticle Measurement

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Goal of Nanoparticle Measurement

- Are nanoparticles in the workplace?
- If so,
  - what is their size and concentration?
  - what is their chemistry and physical structure?
  - how are they temporally and spatially distributed?
  - where did they come from?
Number, Surface, or Mass

Concentration

Particle Diameter, µm

Number

Surface

Mass
Integrated or Size-Resolved

Integrated Concentration
\[ \text{Total Number} \]
\[ \text{Volume} \]

Size-Resolved Concentration
\[ \frac{\text{Number}}{\text{Volume (Size Range)}} \]
Personal or Area Sampling

• Personal Sampling
  – No options currently available
  – Some under development

• Area Sampling
  – Integrated industrial hygiene instruments
  – Size-resolved research devices
Line Losses

Tube dimensions
Diam = ¼ in = 0.64 cm
Length = 20 in = 50 cm
Airflow = 0.7 Lpm
## Instruments to Measure Nanoparticles

<table>
<thead>
<tr>
<th></th>
<th>Manual</th>
<th>Direct-reading</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Integrated</strong></td>
<td>none</td>
<td>Condensation particle counter (CPC)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Diffusion charger (SA)</td>
</tr>
<tr>
<td><strong>Size-resolved</strong></td>
<td>none</td>
<td>Scanning mobility particle sizer (SMPS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electrical low pressure impactor (ELPI)</td>
</tr>
</tbody>
</table>
Condensation Particle Counters

Airflow

Saturator

Condenser

Optics

Alcohol Soaked Wick

Airflow Exit

Integrated Number concentration
Dp < 1 µm

<table>
<thead>
<tr>
<th></th>
<th>P-TRAK</th>
<th>CPC 3007</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost</strong></td>
<td>$6K</td>
<td>$8K</td>
</tr>
<tr>
<td><strong>Lower Size Range</strong></td>
<td>20 nm</td>
<td>10 nm</td>
</tr>
<tr>
<td><strong>Max Conc</strong></td>
<td>5x10^5 p/cc</td>
<td>1x10^5 p/cc</td>
</tr>
</tbody>
</table>

TSI, Inc.
Diffusion Charger

Integrated Surface Area Concentration
10 nm < Dp < 800 nm

Charge on Aerosol $\propto$ Surface Area

Cost $9,000

DC2000 CE Diffusion Charger
EcoChem
Size-Resolved: Scanning Mobility Particle Sizer

Kr-85

Clean Sheath Air

Negatively Charged Rod Attracts Positively Charged Particles

Electrical Force

Drag

Differential Mobility Analyzer (DMA)

Monodisperse Out to CPC

TSI, Inc.

Number by size
3 nm < Dp < 800 nm

$65,000 - $90,000

Scan takes > 3 minutes
Electrical Low Pressure Impactor

Airflow

Corona Charger

Cascade Impactor

Electrometers

Inversion Algorithm

Surface area by size
7 nm < Dp < 10 µm

$75K
Dekati, Inc.
Size-Resolved: Under Development

• Passive samplers
  – Collect particles by diffusion
  – Analysis by transmission electron microscopy (TEM)
  – Very low-cost, personal sampling
  – Chemistry available

• Time-of-flight mass spectrometers
  – Couple SMPS with mass spectrometer
  – Chemistry of individual particles
  – Expensive ~ $500,000
Nanoparticle Sampling Devices

0.001  0.01  0.1  1 µm
1  10  100  1000 nm

Passive sampler and microscopy

Increasing $$$

Industrial Hygiene Instruments
- CPC
- Diffusion charger

Research Instruments
- SMPS
- ELPI

ATOF-MS

Surface Area based
Number based
Sampling Case Study

- International Truck and Engine Corporation
- Engine Machining and Assembly Center
- Produces 1,000 engines per day

New Transfer Lines
2001 $300M Renovation

Older Retrofitted Enclosures

870 ft x 1,200 ft
1,000,000 ft²

Assembly Area
Mobile Sampling Cart

<table>
<thead>
<tr>
<th>Surface Area Concentration</th>
<th>Bulk Number Concentration</th>
<th>Number Concentration by Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 nm &lt; D_p &lt; 1 µm</td>
<td>10 nm &lt; D_p &lt; 1 µm</td>
<td>300 nm &lt; D_p &lt; 10 µm</td>
</tr>
</tbody>
</table>

- **Diffusion Charger**
- **Condensation Particle Counter**
- **Diluter**
- **Optical Particle Counter**

- **Laptop**
- **AC/DC Inverter**
- **Marine Deep-cycle Battery**
Concentration Maps – CPC: Ultrafines

Temporal Variability Low

Older Retrofitted Enclosures
New Transfer Lines
Assembly
Ultrafines Compared to Larger Particles

CPC: Ultrafines
- Older Retrofitted Enclosures
- New Transfer Lines
- Assembly

Grimm OPC: 1 µm to 3 µm

High ultrafine only in new transfer line area

Larger visible mist from machining in older area
Ultrafines By Season

December, 2004
Outdoor Temp = -1°C

Older Retrofitted Enclosures

New Transfer Lines

Assembly

March, 2005
Outdoor Temp = 22°C

p / cc
-1,000,000
-800,000
-600,000
-400,000
-200,000
0
Ultrafines From Gas-Fired Burners

Exhaust Air

Low Efficiency Filters

Gas-Fired Burners

Chiller

Outside Air (OA)

Return Air (RA)

Aerosol Equipment

Conditioned Air to Plant

Plant Ceiling
Ultrafines From Gas-Fired Heaters

![Graph showing ultrafines emissions over time with markers for Burner On and Off, Accidental Burner On/Off, and CPC p/cc levels from 9:30 to 12:30.](image-url)
Measuring Nanoparticles: Summary

• Sampling methods are limited to area devices
  – Industrial hygiene $\rightarrow$ integrated concentration
  – Research grade $\rightarrow$ size-resolved concentration

• Aerosol mapping is useful
  – Assess occupational concentrations
  – Identify sources

• New methods are needed
  – Low-cost, personal sampler