Aerosol Short Course: Physics, Measurement, and Sampling

Boeing Ed Wells Course

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II. Measurement
Overview

• Background and Physics

• Measurement

• Sampling
Measuring Aerosols

- The goal is to measure the concentration and size distribution of an aerosol.

<table>
<thead>
<tr>
<th>Particle Diameter</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.001</td>
<td>1</td>
</tr>
<tr>
<td>0.01</td>
<td>10</td>
</tr>
<tr>
<td>0.1</td>
<td>100</td>
</tr>
<tr>
<td>1</td>
<td>1000</td>
</tr>
<tr>
<td>10 µm</td>
<td>10^4 nm</td>
</tr>
</tbody>
</table>

Ultrafine | Fine | Coarse
Methods to Measure Aerosols

• Manual Methods
  – Physically collect particles
  – Weigh on microbalance
  – Perform chemical analysis

• Automatic Methods
  – Use some property of aerosol
  – Obtain a direct readout
Filters

Air + Particles

Impaction

Diffusion

Collection Efficiency

Air

HEPA

Diameter

Diffusion

Impaction
Mass Concentration

Pull air through a filter

\[ C_{\text{mass}} = \frac{M}{Q \cdot t} \]

- Weight gain on filter
- Air flow rate
- Sample time

Inhalable – IOM sampler

To Pump
Size Selective Sampling

- Threshold Limit Values (OSHA)
  - Inhalable
  - Thoracic
  - Respirable

- National Ambient Air Quality Standards (EPA)
  - PM10
  - PM2.5
Size Selective Samplers

- **Impactors**

  - Large particles hit plate
  - Small particles reach filter

- **Cyclones**

Size Selective Samplers

• Virtual Impactors

Virtual Plate

Major Q
Fines

Minor Q
Coarse Particles

• Biological Samplers

Large particles hit agar Pietri

Small particles reach filter

Agar Pietri

Filter
Size Distribution Measurement

- So far, only bulk mass concentration
  - Collect everything smaller than a certain size

- How do we get a size distribution?
# Cascade Impactor

Andersen 8-stage non-viable

@ 28.3 Lpm

<table>
<thead>
<tr>
<th>Stage</th>
<th>Lower $d_{50}$ μm</th>
<th>Upper $d$ μm</th>
<th>Particle Weight in Bin mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>9.0</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5.8</td>
<td>9.0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4.7</td>
<td>5.8</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3.3</td>
<td>4.7</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2.1</td>
<td>3.3</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.1</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.7</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.4</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>Filter</td>
<td>--</td>
<td>0.4</td>
<td></td>
</tr>
</tbody>
</table>

Directly measure mass distribution

[Image of Cascade Impactor]
Microscope

- Light
- Electron
  - Scanning
  - Transmission

<table>
<thead>
<tr>
<th>Bin</th>
<th>Lower ( d ) ( \mu \text{m} )</th>
<th>Upper ( d ) ( \mu \text{m} )</th>
<th>Particle Count in Bin</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2.5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.5</td>
<td>1</td>
<td></td>
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</tbody>
</table>
Summarize Data

50% mass < MMD  50% mass > MMD

MMD, Mass Median Diameter

\[ MMD = d_{50} \]

GSD, Geometric Standard Deviation

\[ GSD = \frac{d_{84}}{d_{50}} = \sqrt{\frac{d_{84}}{d_{16}}} \]
Log Probability Paper

http://myweb.uiowa.edu/tpeters/IH1/Aerosols/logprob.pdf
Cascade Impactor Example

http://myweb.uiowa.edu/tpeters/IH1/Aerosols/ParticleSizeDistribution.xls

Gas / Particle Sampling

Gas

Denuder

Filter

Sorbent

Adsorption of 95% gas
Pass 95% particles

Particle

Adsorbed Vapor
New Passive Sampler

- Large particles settle
- Intermediate-sized particles affected by turbulent inertia
- Small particles diffuse

Mesh Cap → Deposition Surface → SEM Stub

$20
Passive Sampler: Microscopic Analysis

- Take digital photo with TEM
- Size particles with Image J software
- Surface Loading
- Chemistry Information Available with EM
- Diameter
Passive Sampler: Airborne Concentration

\[ F = \frac{SL}{t} = \left( \frac{\#}{\text{cm}^2} \right) \left( \frac{s}{s} \right) \]

\[ C = \frac{F}{V_{\text{dep}}} = \left( \frac{\#}{\text{cm}^2 \text{s}} \right) \left( \frac{s}{\text{cm}} \right) = \frac{\#}{\text{cm}^3} \]

Deposition Velocity = \( f(\text{diameter}) \)

Particle Diameter, \( \mu \text{m} \)

Number

Mass
Passive Sampler Monitoring

- Environmental pollutants
- Occupational contaminants
## Manual Methods Summary

<table>
<thead>
<tr>
<th>Method</th>
<th>Information</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size selective samplers</td>
<td>Bulk mass concentration</td>
<td>Direct</td>
<td>Expensive, bulky equipment</td>
</tr>
<tr>
<td>Impactors</td>
<td>Mass distribution</td>
<td>Direct</td>
<td>Expensive and time consuming</td>
</tr>
<tr>
<td>Passive samplers</td>
<td>Size distribution, Chemistry</td>
<td>Low-cost</td>
<td>Less precision</td>
</tr>
</tbody>
</table>
Automatic or Direct-Reading Instruments

• Provide near real-time indication of particles

• Provide information on variability of particles
  – Spatial
  – Temporal

• Not compliance instruments
Types of Instruments

• Bulk concentration
  – Particle counters - number concentration
  – Aerosol photometers - mass concentration

• Sizers – number vs size
  – Optical
  – Electrical

• Aerosol Time of Flight Mass Spectrometry (ATOF-MS)
  – Number sizer
Bulk Concentration: Counters

Bulk number concentration
Dp < 1 μm

Condensation Particle Counter
(TSI CPC 3007)

$5,000 - $7,000
Bulk Concentration: Aerosol Photometers

Bulk mass concentration
0.5 µm < Dp < 10 µm

Figure 1
Flow Through a Photometer

TSI DustTrack

$3,000 - $7,000
Bulk Concentration Output

Number Concentration

Mass Concentration

Time
Sizers: Optical Particle Counter (OPC)

Aerosol Inlet

Incident Light

Number by size
$0.3 \mu m < D_p < 20 \mu m$

Light Stop

PMT

$10,000 - $15,000

Grimm OPC
Sizers: Aerodynamic Particle Sizer (APS, TSI Inc.)

Aerosol
1 Lpm

Sheath Air
4 Lpm

Beam 1
Beam 2

PMT

Number by size
0.5 µm < Dp < 20 µm

TOF

Time

$45,000
Sizers: Electrical Scanning Mobility Particle Sizer (SMPS)

Number by size
3 nm < Dp < 800 nm

Negatively Charged Rod Attracts Positively Charged Particles

Scan takes > 3 minutes
$65,000 - $90,000
Sizers: Electrical Multiple DMA

Number by size
3 nm < Dp < 800 nm

Good for exhaust because fast response

New distribution several times per second

$100,000 – $200,000
Output From Sizers

Pittsburgh, Aug 10, 2001

Particle Size (nm)

Time of Day

Particle Size (nm)

Response $dN/d\log D_p$ (cm$^{-3}$)

Response $dN/d\log D_p$ cm$^{-3}$

Particle Size (nm)
Figure 1: Diagram of AMS

Aerodyne Aerosol Mass Spectrometer

~ $500,000
Aerosol Measurement Summary

1 10 100 1000 nm
0.001 0.01 0.1 1.0 µm 10 100 1000 µm

- Passive samplers and microscopy
- Filters & size selective samplers
- Photometer
  - OPC
  - APS
- CPC
- SMPS
- Multiple DMA
- ATOF-MS

Increasing $$$

Bulk Conc. Mass-Based