Development, Characterization, and Application of a Light Scattering Module within the Aerodyne AMS

Eben Cross
6th AMS User’s Meeting 2005
08/27/2005

Simple Rules to giving a Successful and Entertaining User’s Meeting Presentation

• Maintain your composure at all times
  – 1. Don’t chew gum\(^1\)
  – 2. Don’t use your foot as a laser pointer\(^1\)
  – 3. Avoid using four-letter words to describe igor plots of you data\(^1\)
    • “This plot is complete #!@&”
  – 4. Avoid using four-letter words in describing the physical geometry of your system\(^2\)
    • “There are some big $#! holes in the ellipsoid”
  – 5. Find some way to make fun of Doug during your talk\(^1,2,3,4,5,...\)

\(^2\)Cross, E. AMS Poster Presentation, Forschungszentrum Julich, Germany Aug 2005.
Overview

- Review system geometry
- LS-AMS Capabilities
- Laboratory Aerosols (Sensitivity Analysis)
  - Refractive Index
  - Shape
- Ambient Aerosol Analysis with a LS-AMS
  - Chebogue Point, Nova Scotia
LS-AMS System Capabilities

1. Provides an independent measure of the particle size ($\sim d_m$) based on the light scattering signal intensity
2. Provides an in-situ measure of the effective density of the aerosol distribution
3. Provides an in-situ quantification of the refractory/particle bounce events within the AMS

An independent measure of the particle size ($\sim d_m$) based on the integrated light scattering signal

$\int f(size, \text{refractive index, shape}) \, ds$
LS-AMS System Capabilities

1. Provides an independent measure of the particle size (~ $d_m$) based on the light scattering signal intensity
2. Provides an in-situ measure of the effective density of the aerosol distribution

In-situ measure of the effective density

Eqn 1. $d_{va} = d_m \times \rho \times S$

Eqn 2. $d_{va} = \rho_{eff} \times d_m$

Time of threshold crossing determines particle velocity $\Rightarrow d_{va}$
LS-AMS System Capabilities

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Point for Discussion

• Classification of the vacuum aerodynamic diameter based on light scattering signals
  – Remove the uncertainty in $t_0$ from the chopper
  – Estimates of vaporization/ion flight times as correction to the light scattering signal velocity designation

Overview

• Review system geometry
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  – Refractive Index
Size detection limit ~ 200 nm

Refractive index effect on LS-AMS sizing method: spherical particles
Refractive index effect on LS-AMS sizing method:
spherical particles

Integrated Light Scattering Signal

- Oleic Acid $n = 1.46$
- PSL $n = 1.59$
- Fomblin $n = 1.3$
- $n_{\text{H}_2\text{O}} = 1.33$
- $n_{\text{ambient aerosol}} \geq 1.42$

$d_m$ (nm)
Refractive index effect on LS-AMS sizing method: spherical particles

Integrated Light Scattering Signal

- Oleic Acid $n = 1.46$
- NH$_4$NO$_3$ $n = 1.554$
- PSL $n = 1.59$
- Fomblin $n = 1.3$
- Nitrate Calibration Curve $n_{ambient aerosol} \geq 1.42$

\[
2 \times 10^6 \\ 3 \\ 4 \\ 5 \\
\text{d}_m (\text{nm})
\]

\[
y = y_0 + A \times x^{\text{pow}}
\]

\[
\text{LS}_\text{signal} = y_0 + A \times \text{d}_m^{\text{pow}}
\]

\[
\text{d}_m = \left( \frac{\text{LS}_\text{signal} - y_0}{A} \right)^{1/\text{pow}}
\]

\[
d_m = \left( \left( \text{LS signal} + 0.032107 \right) / 6.7614 \times 10^{-10} \right)^{1/3.4926}
\]
Error in LS-AMS sizing due to refractive index difference

\[ 1.4 < n < 1.6 \]

Error in the LS-AMS sizing = +8/-5%

Experimental Fit: slope = 1.03; \( R^2 = 0.991 \)

LS-AMS Material Density Determination

- Oleic Acid = 0.894
- PSL = 1.03
- Fomblin = 1.85

AMS-LS (from Nitrate Calibration Curve)
- OA = 0.85
- PSL = 1.03
- Fomblin = 2.03
Error in LS-AMS density determination

LS-AMS density vs SMPS-AMS density

Nitrate Calibration (1.3 < n < 1.6)
Curve Fit: slope = 1.0556; R^2 = 0.999948

Nitrate Calibration (1.4 < n < 1.6)
Curve Fit: slope = 0.97885; R^2 = 1

Error in LS-AMS density determination 1.4 < n < 1.6 = +0/-5%

Point for Discussion

• Comparison of the mie scattering curves with the experimental scattering signals for spherical particles
  – Collection geometry specifics
  – Potential for LS-AMS determination of optical properties (refractive index)
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Effect of particle beam divergence on the LS-AMS sizing method

1. Lower light scattering signal intensity
2. Larger variance in light scattering signals

![Graph showing the effect of particle beam divergence on the LS-AMS sizing method](image-url)

- NH₄NO₃ n = 1.554
- (NH₄)₂SO₄ n = 1.53
Evaluation of Particle Beam Divergence

<table>
<thead>
<tr>
<th>composition</th>
<th>refractive index</th>
<th>% T</th>
<th>Center</th>
<th>Sigma</th>
<th>CE_vaporizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH4NO3 346nm</td>
<td>1.554</td>
<td>0.0</td>
<td>0.01</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>(NH4)2SO4 346nm</td>
<td>1.53</td>
<td>0.62</td>
<td>~0.7</td>
<td>~1.0</td>
<td></td>
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0.5 mm wire in center blocking position

Evaluation of Particle Beam Divergence

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LS sig

0.5 mm wire in center blocking position
Effect of particle beam divergence on the LS-AMS sizing method

Error in LS-AMS sizing due to particle beam divergence = +0/-9%

Effect of shape and refractive index on LS-AMS sizing
Effect of shape and refractive index on LS-AMS effective density measurement

Summary of Laboratory Results

- Validated the use of a general calibration curve based on NH₄NO₃ particles for LS-AMS sizing and subsequent density measurements
  - Material densities for spherical (S=1) particles determined to within
    - $\rho = +0/-5\% \ (1.4 < n < 1.6)$
  - Effective densities of nonspherical (S<1) particles
    - $\rho_{eff} = +/-7\% \ (1.4 < n < 1.8)$ and (0.1 < $\sigma$ < 0.7)
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Field Application of the LS-AMS

• Objectives
  – Test the application of an NH$_4$NO$_3$ calibration curve to ambient aerosol characterization
  • Provide a continuous measure of the effective density of the ambient aerosol distribution
  • Provide an in-situ quantification of the refractory number and/or particle bounce events
Southwesterly Flow: Anthropogenic Dominated

NEAQS-ICARTT (July 11 – August 15, 2004)
Ground Site: Chebogue Point, Nova Scotia

Partial Time Trend for the Experiment

SO$_4$
Org
NH$_4$
NO$_3$

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Partial Time Trend for the Experiment

Effective Density Chemical Composition

Partial Time Trend for the Experiment

Effective Density LS-AMS

Effective Density Chemical Composition
Comparison of Effective Density Measurements

Designation of six distinct plume events
CE for Sulfate Dominated Plumes

Average CE_bounce ~ 0.47 +/-0.05

Designation of six distinct plume events
Summary of Field LS-AMS Analysis

- LS-AMS allows a continuous measurement of the effective density of ambient aerosol distributions based on a single NH$_4$NO$_3$ curve for optical size calibration
  - Mixed sulfate organic (characterized by southwesterly flow over urban population centers)
    - $\rho_{\text{eff}} = 1.59 \text{ g/cc}$
  - Organic-dominated (characterized by northwesterly flow over remote continental land regions)
    - $\rho_{\text{eff}} = 1.4 \text{ g/cc}$
- LS-AMS counting method provides an in-situ measurement of $ce_{\text{bounce}}$
  - Mixed sulfate-organic plumes: $ce_{\text{bounce}} \sim 0.47 +/- 0.05$
  - Organic-dominated: $ce_{\text{bounce}} \sim 0.28 +/- 0.04$