Collection efficiency of SP-AMS for internally mixed particulate black carbon

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CE issue: Tungsten vaporizer vs. laser vaporizer

**CE issue: Particle bounce off from tungsten vaporizer**

Particle beam

**CE issue: Particle beam – SP laser overlap**

Particle beam

\[ d_{PB} > d_{LB} \rightarrow \text{What is the collection efficiency of laser vaporizer for BC?} \]
Objectives of this work

• To understand the effects of mixing state of aerosol particles (bare BC vs. internally mixed BC) on the quantification of atmospheric BC using SP-AMS.

• To provide insights for evaluating the current calibration procedure for atmospheric BC quantification.
Experimental setup

BC standard: Regal black
Coating: Bis(2-ethylhexyl)sebacate (BES)
SP-AMS configuration: Dual vaporizers

Coating thickness depends on temperature

Measures particle mass before and after coating
## Summary of coating experiments

Lens transmission ≈ 1

<table>
<thead>
<tr>
<th>Regal Black Core Size (d_m, nm)</th>
<th>Final d_\text{va} (nm)</th>
<th>f_{RB}</th>
</tr>
</thead>
<tbody>
<tr>
<td>250, 300, 400</td>
<td>180, 205, 255</td>
<td>1.0</td>
</tr>
<tr>
<td>300</td>
<td>222</td>
<td>0.88</td>
</tr>
<tr>
<td>300</td>
<td>255</td>
<td>0.72</td>
</tr>
<tr>
<td>300</td>
<td>313</td>
<td>0.52</td>
</tr>
<tr>
<td>300</td>
<td>355</td>
<td>0.33</td>
</tr>
<tr>
<td>200</td>
<td>285</td>
<td>0.26</td>
</tr>
<tr>
<td>150</td>
<td>275</td>
<td>0.20</td>
</tr>
<tr>
<td>75</td>
<td>250</td>
<td>0.15</td>
</tr>
</tbody>
</table>

\[ f_{RB} = \text{mass of black carbon/total mass of black carbon and organics} \]
Sensitivity to Regal Black (RIE_{BC})

Increasing coating thickness

Increasing sensitivity
Beam Width Probe (BWP) Measurement

Mass concentration of species “s”

\[ C_s = \frac{1}{C_E s \cdot R I E_s \cdot m I E_{NO_3} \cdot Q} \sum_i I_{s,i} \]

\[ C E = E_L \cdot E_S \cdot E_B \]

\( E_L \) = Aerodynamic lens transmission
\( E_B \) = Particle bounce off the vaporizer
\( E_S \) = Particle beam divergence

\( E_L \approx 1 \) (Dva = 180-355 nm)
\( E_B = 1 \) (no bouncing issue on laser vaporizer)

\( E_S \) governs the overall CE for black carbon
\[ \rightarrow \text{Beam width probe measurement} \]
Beam Width Probe (BWP) Measurement

**Graph:**
- **Y-axis:** Signal Transmission (%)
- **X-axis:** BWP Position (mm)
- **Legend:**
  - Ammonium Nitrate
  - 200 nm Regal Black
  - Coated 200 nm Regal Black

**Table:**

<table>
<thead>
<tr>
<th></th>
<th>NO$_3$</th>
<th>RB</th>
<th>RB with coating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block % at the center</td>
<td>91</td>
<td>60</td>
<td>89</td>
</tr>
<tr>
<td>Beam sigma (mm)</td>
<td>0.24</td>
<td>0.38</td>
<td>0.25</td>
</tr>
<tr>
<td>95% beam width (mm)</td>
<td>0.94</td>
<td>1.51</td>
<td>0.99</td>
</tr>
</tbody>
</table>
BWP Measurement (from Aerodyne)

Increasing sensitivity (RIE)

Decreasing particle beam width/
Increasing particle – laser beam overlap

0.41 mm diameter wire
Located at center of particle beam

rBC Signal transmission

rBC ions / pg
Particle beam width comparison

- 300 nm Regal Black
- 200 nm Regal Black
- Coated 200 nm RB ($f_{BC}$ ~ 0.2)
- Ambient black carbon (Toronto)
- 300 nm NH$_4$NO$_3$

300 nm Regal Black
200 nm Regal Black
Coated 200 nm RB
Ambient black carbon
300 nm NH$_4$NO$_3$

Laser beam width $\sigma < 0.25$ mm

Note: RIE saturated for $f_{BC} < 0.6$

Particle beam width of ambient BC is similar to that of coated 200 nm regal black.
Particle Beam Width Comparisons

- Particle beam widths: DOS coated RB ~ pure DOS/AN particles
- Laser beam width is $\leq \sigma \sim 0.1$ to 0.25 mm

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SP-AMS vs. SP2 Mass Loadings

CalNex2010

The CE is low when size is small.

Massoli et al., 2012
Sensitivity to BES coating ($\text{RIE}_{\text{organics}}$)

Increasing coating thickness

$\text{RIE}_{\text{organics}}$ increases as coating thickness increases in a similar manner.
Org and rBC signal transmissions decrease together with increasing DOS coating and narrowing of particle beam, suggesting that the effective particle beam widths for rBC and DOS are similar.
Taking into account changing RIE for rBC and BES as the particle beam becomes narrower. SP-AMS can provide an accurate quantification of rBC down to 5% by mass for internally mixed particles.
Summary

• The collection efficiency of the SP-AMS is a function of the mixing state of rBC particles. Organic coating can narrow the particle beam width of BC, increasing the degree of laser beam – particle beam overlap.

• Ambient black carbon and thickly coated regal black particles have similar particle beam width, highlighting the importance of evaluating the current calibration procedure for rBC quantification.

• BWP measurements suggest that the effective SP-laser beam width (sigma) is ≤ 0.25 mm. Further investigation is required.

• Given accurate RIE values for lab-generated rBC particles and organic coating, the SP-AMS can provide an accurate quantification of rBC down to 5% by mass for internally mixed particles.